BIOLOGY

A TEXTBOOK FOR HIGHER SECONDARY SCHOOLS

(*Classes XI—XII*)

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Section I

Anatomy and Physiology: Animals

CHAPTER 1

Microscopic Structure of Mammalian Tissues

The complex structure and function of an animal body can only be understood in the right perspective by a study of the structural organisation of each part at the gross, light microscopic and electron microscopic levels. This is a prerequisite for the correlation of the structure with the functions of any organ of the body. This correlative approach has been adopted in all chapters of this book.

Individual cells are the basic units of both the structure and the function of plants and animals (Fig. 1.1). The structure of the cell as well as its organelles has been described in earlier classes and will be further elaborated in the textbook for class XII. Certain fundamental principles are common to almost all cells and represent the minimal requirements for maintaining the integrity of a cell. Thus, all cells are remarkably similar in their means of exchanging materials with their immediate environments, of obtaining energy from organic nutrients, of synthesising complex proteins, and of duplicating themselves. However, the significant differences between a liver, a muscle and a nerve cell represent specialisations for performing specific roles, for example, the excitability of nerve cells and conduction of impulses, the transport of food molecules across the cells of the intestine, the synthesis of specific substances by specific cells, the contractivity of muscles, etc.

A body consists of various types of specialised cells, each type differing in structure and function from the other. Four main types of tissues are recognised, namely, (i) *epithelial tissues*, (ii) *connective tissues*, (iii) *muscle tissues*, and (iv) *nerve tissue*. A number of different cell types and tissues form larger functional units called *organs*, e.g., heart, liver, kidney, pancreas, skin, etc. A collection of organs which together subserve a particular function forms the organ system, e.g., kid-

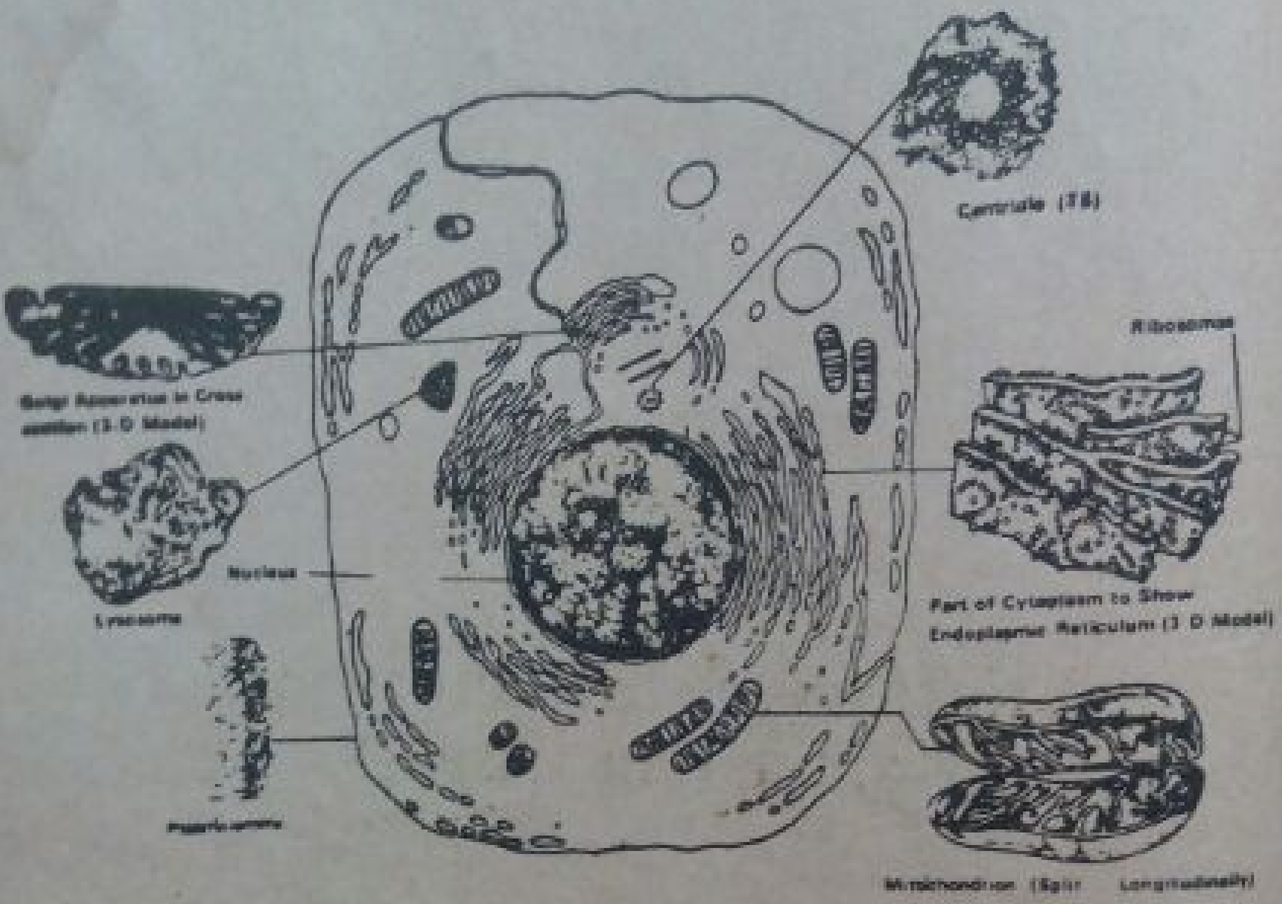


Fig. 1.1 Diagrammatic representation of some common organelles and structures of a cell as seen under electron microscope

neys, urinary bladder, ureters constitute the *urinary system*.

The study of the microscopic structure of tissues and organs is called *histology*. The histological structure and functions of tissues and organs found in a mammal are described in this chapter.

Epithelial Tissues

Epithelial tissue or epithelium consists of cells which are closely applied to each other with no intervening material. The epithelial tissue (Fig. 1.2) covers the surface of the body, ducts, vessels and the body cavities. The epithelial cells rest on a supporting connective tissue called the *basement membrane*. The free surface of the cells may be smooth or may contain *cilia*, *stereocilia* or *microvilli* according to the function of the cells (Fig. 1.2a). Cilia are protoplasmic projections with a small granule at the base of each cilium. The *motile cilia* are associated with the respiratory organs and the reproductive tract. Cilia help in the passage of mucus and other substances along the surface of the cell due to their ciliary movement.

Stereocilia are elongated, nonmotile cilia which are broad at the base and taper gradually to a fine wavy filament which lacks the basal granule. Stereocilia are found in some parts of the male reproductive tract such as the epididymis and the vas deferens. *Microvilli* are extremely thin, short, closely packed protoplasmic projections. They are found in locations where absorption and secretion are the major activities of the cell.

The epithelia are divided into two main groups: *Simple epithelia* and *stratified epithelia*. *Simple epithelia* consists of a single la

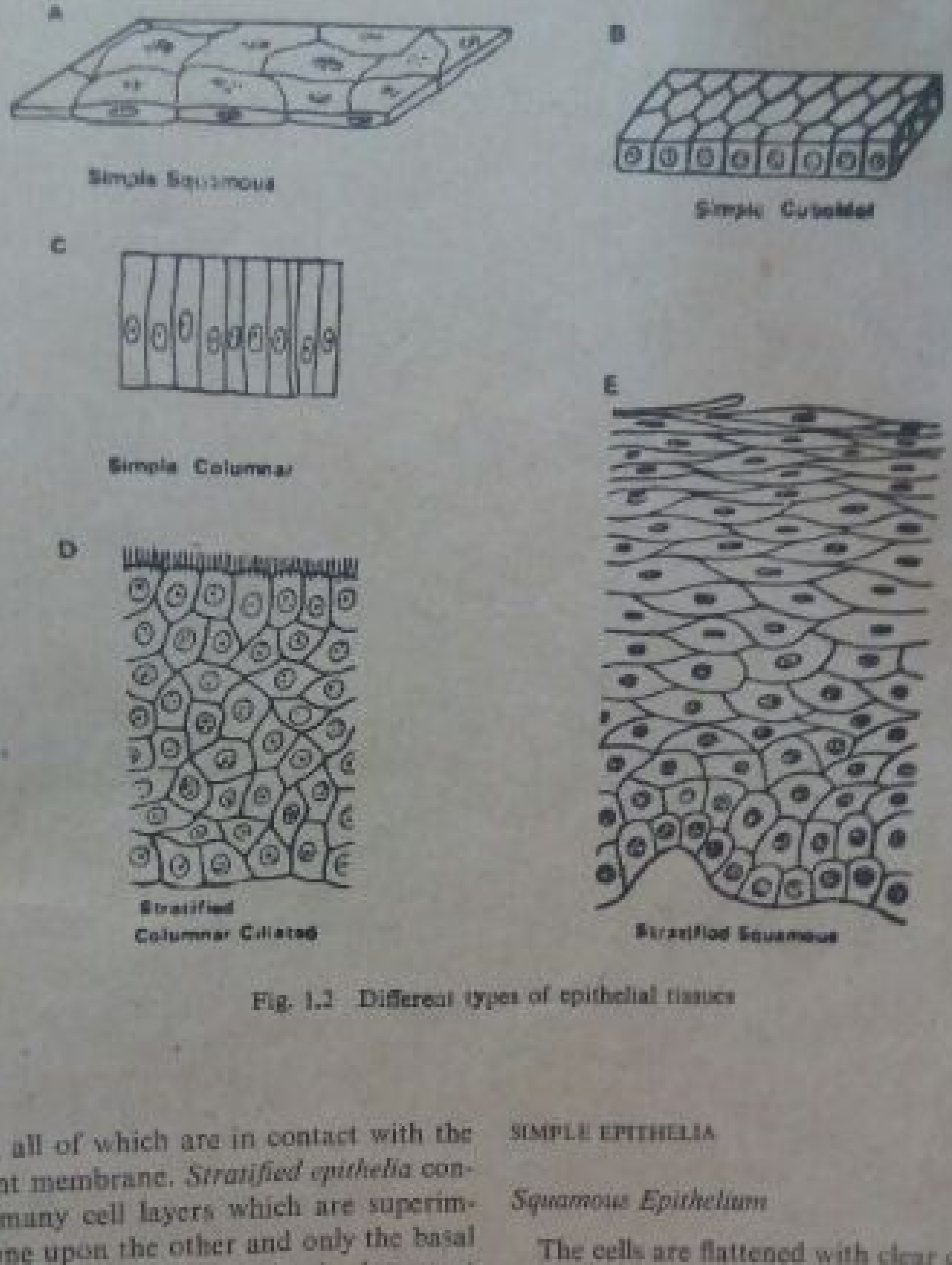


Fig. 1.2 Different types of epithelial tissues

of cells, all of which are in contact with the basement membrane. *Stratified epithelia* consist of many cell layers which are superimposed one upon the other and only the basal cell layer is in contact within the basement membrane. The two major groups of epithelia are further subdivided according to the shapes of the component cells as shown below:

Simple Epithelia	*Stratified Epithelia*
Squamous	Stratified columnar
Cuboidal	Stratified cuboidal
Columnar	Stratified squamous

SIMPLE EPITHELIA

Squamous Epithelium

The cells are flattened with clear cytoplasm and centrally located, single round or oval nucleus. The squamous epithelium is found in the lung, Bowman's capsule and tubules of the kidney. Generally, the squamous epithelium forms barriers in regions where diffusion or filtration is taking place (Fig. 1.2A).

Cuboidal Epithelium

In a vertical section, the cells appear cuboid with a central nucleus (Fig. 1.2B). In surface

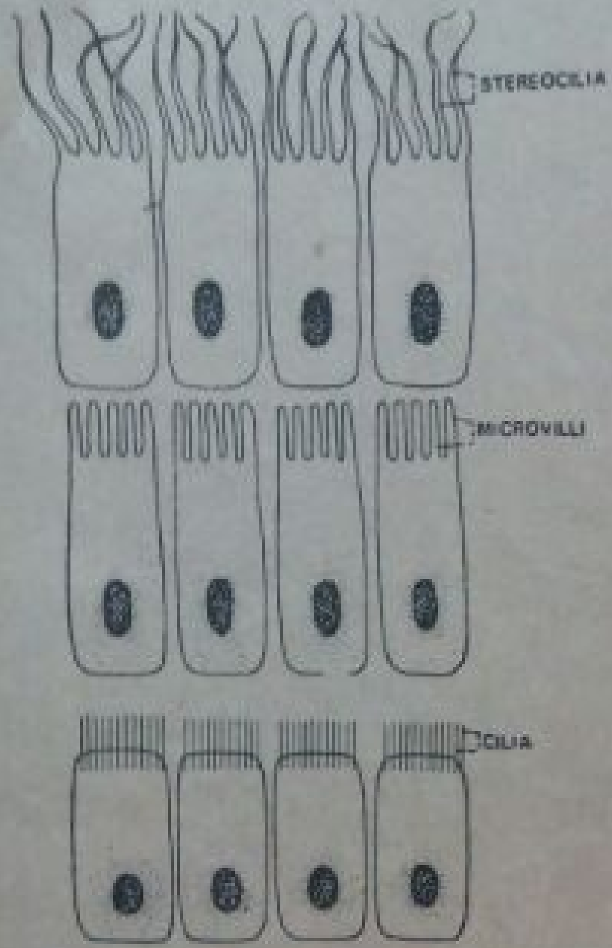


Fig. 1.2 Epithelial cells showing projections in the form of stereocilia, microvilli and cilia

view, the cells appear hexagonal. The cuboidal epithelium is found in certain kidney tubules and in many glands and their ducts.

Columnar Epithelium

The cells are tall with an oval nucleus located almost at the same level (Fig. 1.2C). This epithelium lines the digestive tract and large ducts of many glands. It has an absorptive or secretory function. The free surface of the columnar epithelial cells may have cilia, e.g., in the fallopian tube or may have mucus-secreting goblet cells as in the intestine.

STARTIFIED EPITHELIUM

Stratified Columnar Epithelium

The superficial layer of this tissue consists of tall columnar cells with no contact with the basement membrane (Fig. 1.2D). This layer covers several deeper layers of irregular spindle-shaped of polygonal cells. This type of epithelium is found in parts of the pharynx, urethra and epiglottis.

Stratified Cuboidal Epithelium

This type of epithelium is found in the mammary glands and in ducts of the sweat glands.

Stratified Squamous Epithelium

As shown in Fig. 1.2E, a few layers of the cells towards the basement membrane appear cuboidal or columnar, whereas the surface layers of the cells are flattened squamous epithelial cells. This epithelium is found in the epidermis of the skin, the mouth, oesophagus, a part of epiglottis, cornea, vagina and the female urethra.

Connective Tissue

The connective tissue surrounds other tissues and organs. It is made up of cells and extracellular materials like fibres and ground substance called *matrix*. The connective tissue is divided into two general types based on the nature of the ground substance. If the tissue has a relatively less rigid matrix, showing varying degrees of softness and toughness, it is termed as *connective tissue proper*, but if the matrix is rigid, it is called *supportive connective tissue*. Besides, blood and lymph are fluid *connective tissues* with liquid matrix.

CONNECTIVE TISSUE PROPER

The connective tissue proper is further divided into a *loose connective tissue* and a *dense connective tissue*. These two types of connective tissues possess a variety of cells and three kinds of fibres, namely, collagenous, reticular and elastic, which are present in the matrix.

The fibres: The fibres are of three kinds distinguishable by their appearance and chemical composition. They are *collagenous or white*, *reticular*, and *elastic* or ...

collagenous or white fibres are made up of a special kind of protein called *collagen*. They are long, wavy, non branching and are seen in bundles. On the other hand, the reticular fibres form a fine branching network. The elastic or yellow fibres are long, branching and made up of *elastin*, an albuminoid protein.

The cell types: There are two types of cells, *fixed cells* and *wandering cells*. The fixed cells store materials such as fat and produce the ground substance. The cell types are shown in Fig. 1.3 and their functions are as follows:

Cell type	*Function*
Fibroblasts	Produce fibres and matrix.
Adipose cells	Store fat.
Plasma cells	Synthesise antibodies.
Mast cells	Produce histamine and heparin. Histamine constricts or dilates the walls of blood vessels, while heparin prevents coagulation of blood (see Chapter 4).

Cell type	*Function*
Macrophage or Histiocytes	Ingest cell debris, bacteria and foreign matter.
Lymphocytes	Ingest cell debris, bacteria and foreign matter.

The matrix: The matrix is composed of several polysaccharides, including hyaluronic acid.

1. *Loose Connective Tissue*

The matrix is not dense. This tissue is widely distributed in the body which connects and supports many tissues and organs to resist strain and displacement. Some examples of the loose connective tissue are the *areolar tissue* which appears to be spongy and the *adipose tissue* which has fat storing cells (Figs. 1.4, 1.5)

Areolar Tissue: This tissue has a predominance of white or collagenous fibres. The

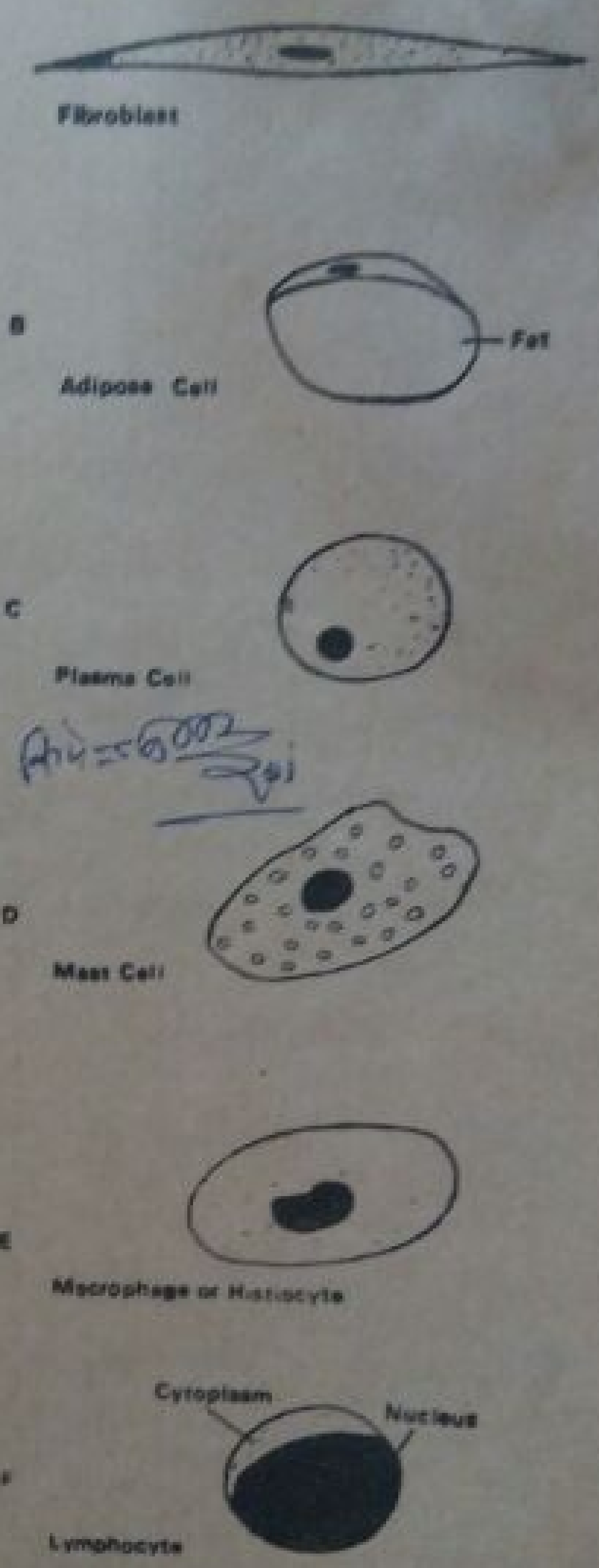


Fig. 1.3 Different cell types found in the connective tissue

Fig. 1.4. Areolar connective tissue

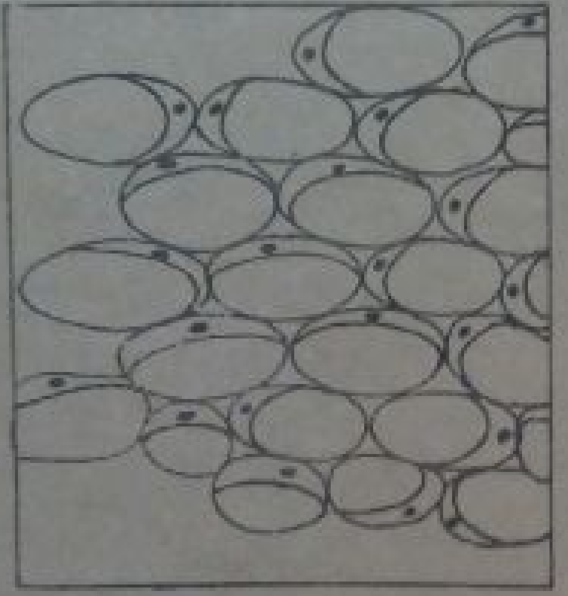


Fig. 1.5 Adipose tissue

areolar tissue is found in mesenteries, in *omenta* of the alimentary canal and in the subcutaneous tissue under the skin.

Adipose Tissue: The adipose tissue has cells which store fat (Fig. 1.5).

2. *Dense Connective Tissue*

There are large bundles of collagen fibres which are regularly or irregularly arranged between the cells, the fibres dominating over the cells and the matrix in quantity (Fig. 1.6).

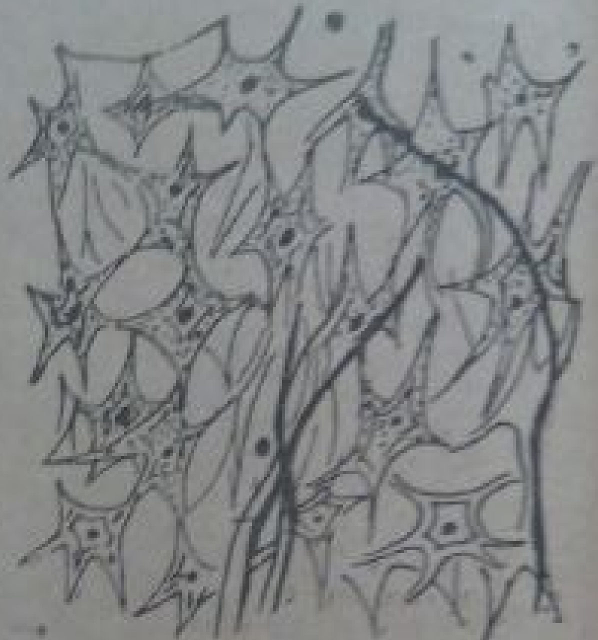


Fig. 1.6. Dense connective tissue

This type of connective tissue is referred to as dense connective tissue and is found in the tendon, ligaments, cartilage and bone.

SUPPORTIVE CONNECTIVE TISSUE

Cartilage

Cartilage is a specialised form of connective tissue and is made up of cells called *chondrocytes* (chondros = cartilage; cytes = cells) which occur in spaces called *lacunae* in the ground substance or *matrix* (Fig. 1.7a, b). There are three kinds of cartilages on the basis of the matrix, i.e., hyaline, elastic and fibrous.

Hyaline Cartilage: The hyaline (glass-like) cartilage has a clear homogeneous matrix and is found at several places such as in *epiphyseal plates* at the extremities of long bones, *larynx* (voice box) and *trachea* (wind-pipe) (Fig. 1.7a).

Elastic Cartilage: This type of cartilage has a matrix of dense, branching, elastic fibres. This cartilage is found in the external ear (*pinna*) (Fig. 1.7 b).

Fibrous Cartilage: The fibrous cartilage is found in regions such as in between the vertebrae and in pubic symphysis. This type of

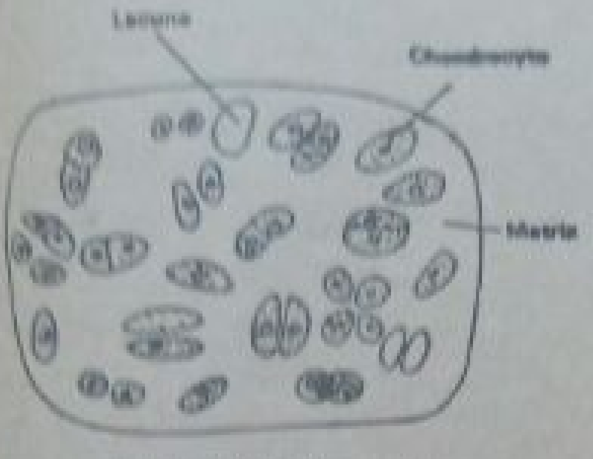


Fig. 1.7 (a) Hyaline cartilage

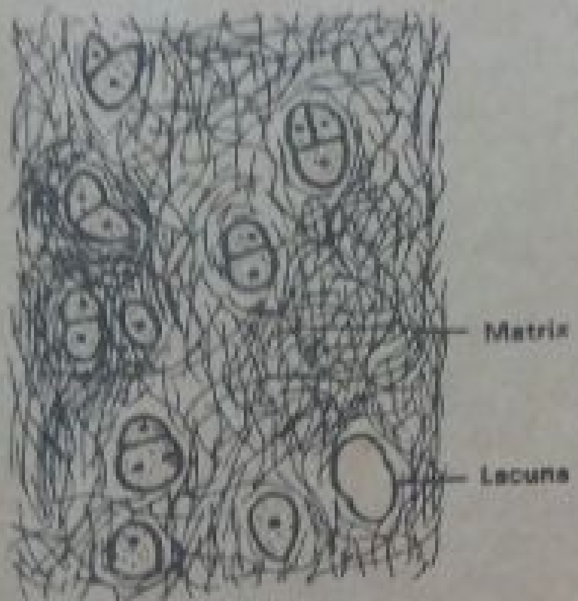


Fig. 1.7(b) Elastic cartilage

cartilage has chondrocytes arranged in rows between bundles of collagen fibres.

BONE

Bone, like other types of connective tissues, is composed of cells, fibres and ground substance. The collagenous matrix is hard and calcified (owing to deposition of calcium salts). Bone cells are called osteocytes. Bone gives shape to the body, provides attachment to muscles and protects the vital organs of the thorax, abdomen as well as the brain. Some bones have a central cavity containing *bone marrow*, which forms blood cells.

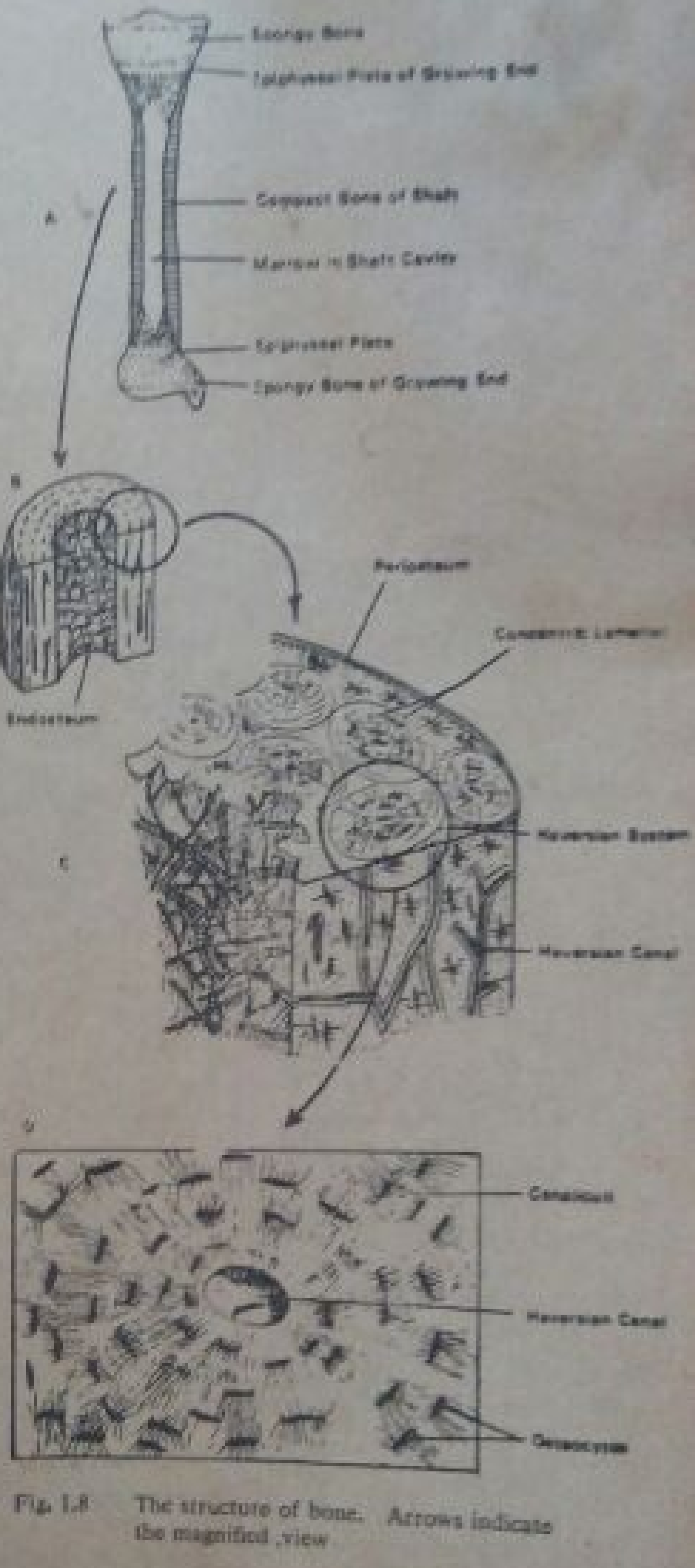


Fig. 1.8 The structure of bone. Arrows indicate the magnified view

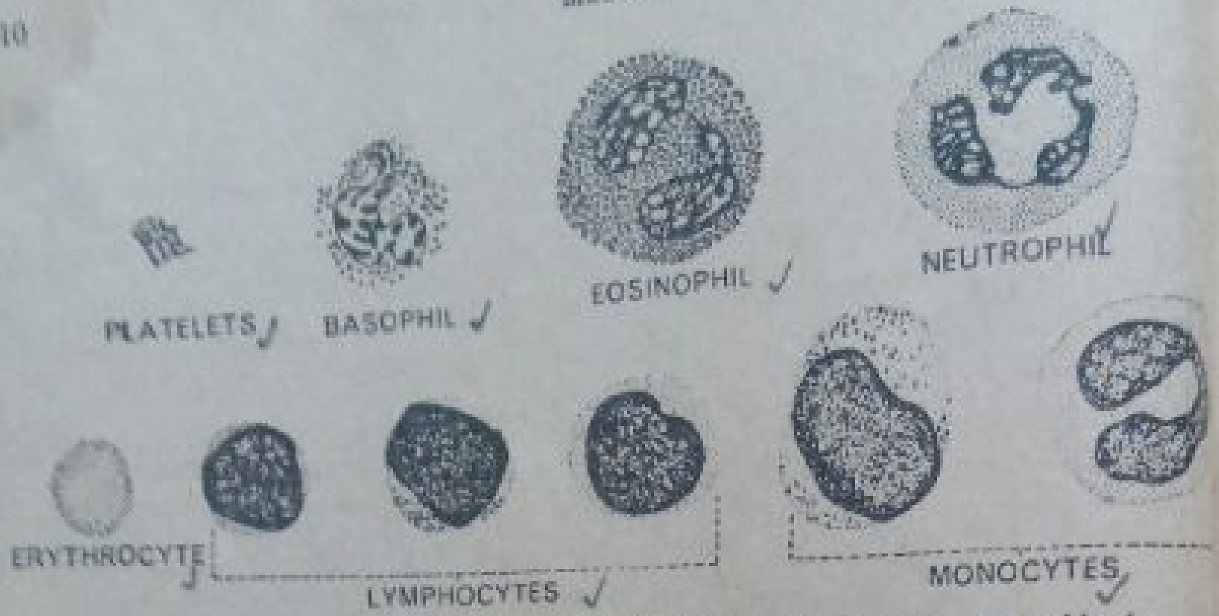


Fig. 1.9 Red blood corpuscles and different white blood corpuscles in the human blood.

Bones are of two types, *spongy and dense*, having the same cells and matrix but differing in their arrangement. In the spongy bone, the marrow cavities are large and irregularly arranged. The bony substance consists of large, slender spicules called *trabeculae*. The *epiphysis* (at the end of the shaft of a long bone) consists of the spongy bone. In the dense compact bone, such as the femur, the marrow cavities are narrow and the bony substance is densely packed with cells and matrix. A thin cross-section of the bone, when examined under the light microscope shows an outer connective tissue covering called the *periosteum*; the layer lining the marrow cavity is the *endosteum*. The Haversian canals (Fig. 1.8), which carry blood vessels and nerves of the bone, are surrounded by a number of concentric *lamellae* of intercellular matrix and bone cells or osteocytes found in lacunae within the lamellae. Delicate protoplasmic processes project into channels called *canaliculi*.

Bone may develop by replacement of chondrocytes of cartilage by osteocytes. Such a bone is called *cartilage* or *replacing bone*, e.g., femur and humerus. The bone may also develop by transformation of the connective tissue. Such bones are called *investing bones*, e.g., bones of the skull.

BLOOD AND LYMPH

Blood and lymph are fluid tissues. Blo[od] has plasma, a fluid medium in which fl[oat] many types of blood cells, mainly red bloo[d] cells (RBC) or *erythrocytes* and the whi[te] blood cells (WBC) or *leucocytes* (leucos= white; cytes=cell) (Fig. 1.9) whose chara[c]teristics and functions are summarised i[n] Table 1.1.

Erythrocytes (erythros=red; cytes=cell) are the cells that appear as biconcave disc[s] having a diameter of approximately 7.7 μ i[n] the human blood. The full grown erythro[-] cytes (in the human blood and in othe[r] mammals) are without a nucleus, although i[n] all other vertebrates they are nucleate[d]. Erythrocytes appear red due to the presen[ce] of a red coloured, oxygen-carrying pigme[nt] called *haemoglobin*. The structural and fun[c]tional details of blood cells have been discu[s]sed in Chapter 4.

Lymphoid organs produce lymph. Th[e] organs such as lymph nodes, spleen, tonsil[s] thymus consist of a *stroma* of the connecti[ve] tissue with reticular fibres and a parenchy[ma] which contains the mass of essential an[d] characteristic cells which carry out the func[-] tional activities of the organ. The cells ar[e] *lymphocytes*, *monocytes*, *macrophages*, *plasma cells* and *eosinophils*. The lymphocytes ...

TABLE 1.1

Different kinds of cells in the human blood

	Erythrocyte	Neutrophil	Eosinophil	Basophil	Monocyte	Lymphocyte	Platelets
Diameter	7-7μ	9-12μ	10-14μ	8-10μ	12-20μ	7-8, 10-12μ	2-4μ
Nucleus	none, in fully grown RBC	multilobed basophilic*	bilobed acidophilic+	multilobed often S-shaped basophilic	kidney-shaped basophilic	round deeply basophilic	none
Granules	none	fine azure coloured	coarse red	coarse purple	fine azure coloured sparse	very sparse fine azure coloured	none
Motility	none	highly active	active	slight activity	slow moving	slow moving	slow
Function	transport of gases	very phagocytic	phagocytic	unknown	phagocytic	formation of antibodies	liberates thrombo-plastin which causes blood clotting
Life span	120-128 days	10-12 hours	14 hours	8-12 days	?	Variable from 3-4 days or more	10-12 days
Differential count in %		50-75	2.5	0-0.5	3.8	20.45	—

*Basophilic = stainable with basic dyes
Total RBC Count 4.5 — 5.4 million/mm

+Acidophilic = stainable with acid dyes
Total WBC Count = 5-10,000/mm

cytes and macrophages are *phagocytic*, i.e., capable of engulfing substances (see Chapter 4 for details).

Blood Cell Formation

Blood cells are formed in the bone marrow of the long bones and the lymphnodules. The processes are called *haemopoiesis* and *lymphopoiesis*, respectively. During haemopoiesis in the bone marrow, the erythrocytes undergo two major changes (a) an increase in the amount of haemoglobin in the cytoplasm and (b) a decrease in the cell size with the loss of the nucleus, so that the erythrocytes circulating in the human blood are *enucleated*.

Muscle Tissues

The muscle tissue is important for all kinds of movement in the body. The muscles can be classified as follows:

Striated	*Non-striated*
1. Voluntary (under control of free will), e.g., all *skeletal* muscles, including some of which are attached to bones	Smooth muscles found in visceral organs such as alimentary canal, uterus, urinary bladder not
2. Involuntary (not under control of free will), e.g., *cardiac* or heart muscle.	

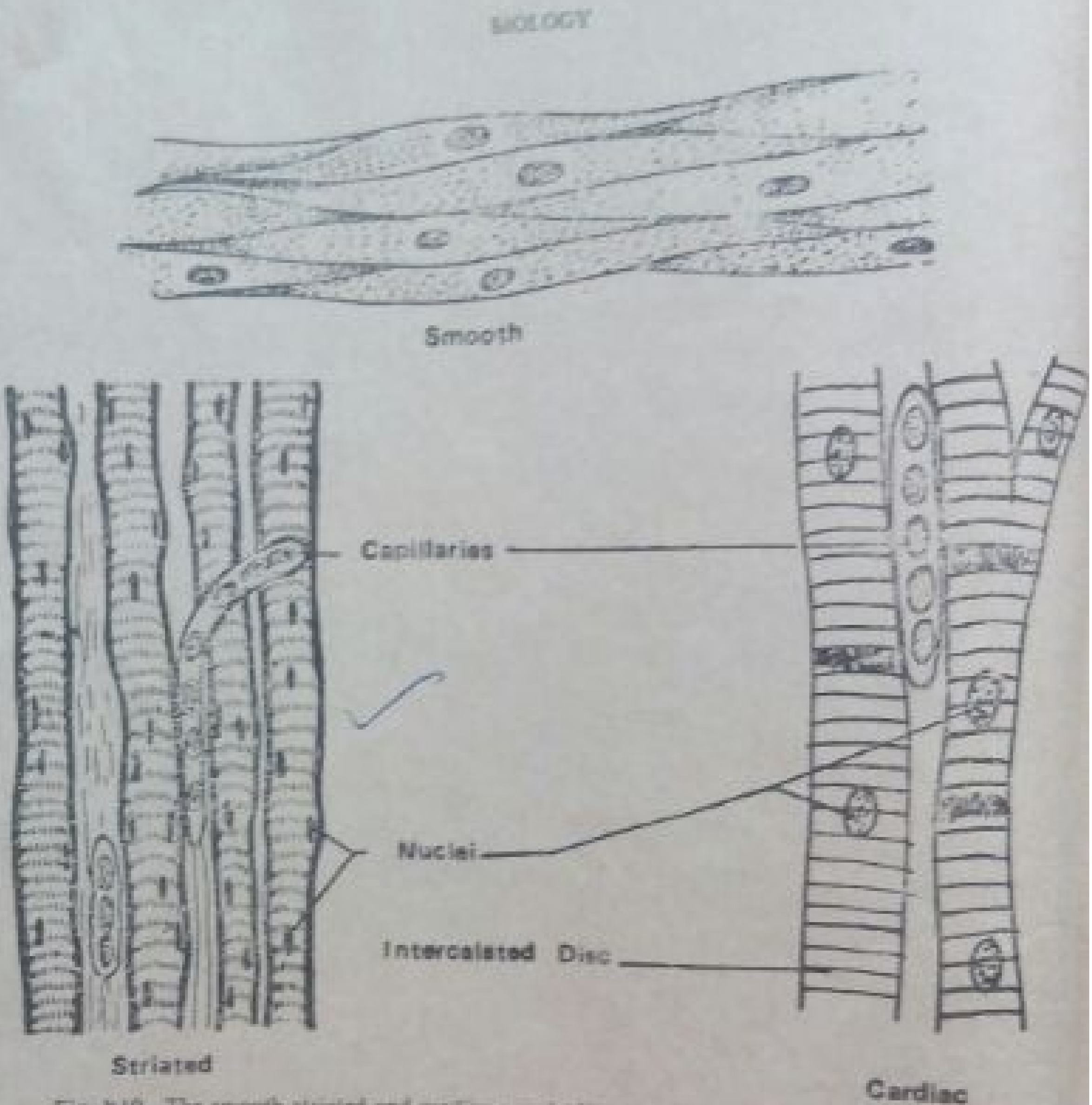


Fig. 1.10 The smooth striated and cardiac muscle fibres seen in the longitudinal section

All the three types of muscles have cells called *muscle fibres* whose characteristic structures are shown in Fig. 1.10. details of the structure and function of muscles have been discussed in Chapter 7.

Nerve Tissue

The nerve cell which is a *neuron* (Fig. 1.11) has a cell body proper and many processes. The smaller processes are branched and are called *dendrites* and the single long one is known as *axon*. The cytoplasm has one nucleus and granules called *Nissl* granules and is continuous in the axon (axoplasm) which contains ncurcfibrils. The axcn nerve fibre may be enveloped by a coveri the *myelin sheath* or *medullary sheath*. It then called as the *medullated* nerve fibre. Th sheath is interrupted by the *Nodes of Ranv* A naked axon, i.e., in without the medull sheath is referred to as the *nonmedulla fibre*. The nerve fibres in the brain and th spinal cord are medullated. Bundles of nerv fibres make up a *nerve*.

The dendrites receive impulses or messag and pass them on to the axon which co ducts them to other neurons or effect organs such as a muscle or a gland.

The Skin

The skin is made up of many cell layers which can be divided into outer *epidermis* and the inner *dermis*. Below the dermis is the layer of fat (*subcutaneous fat*). The thickness of the skin depends on the thickness of the epidermis and dermis.

The epidermis is made up of four distinct layers of epithelial cells. The lowermost is the *Malpighian layer* which has layers of dividing cells. The shape of these cells is shown in Fig. 1.12. This layer helps to add new cells to the epidermis which move out in the direction as shown in the diagram. The next layer is the *stratum granulosum* followed by the clear *stratum lucidum* and the outermost *stratum corneum* made up of dead, flattened cells.

The dermis is made up of the dense irregularly arranged connective tissue. The dermis has skin pigment cells called *melanocytes* which contain the black pigment melanin, nerves, blood and lymph capillaries and coils of the tabular *sweat glands* which pass through the epidermis and open on the surface of the skin (Fig. 1.13). The roots of the hair are embedded in the dermis. The hair is covered by two sheaths or coverings and the hair shaft penetrates the epidermis and juts out on the surface of the skin. At the base of the hair (*hair papilla*) are the openings of the *sebaceous glands* which produce an oily secretion for lubricating the hair.

The nerve endings in the skin carry sensations of touch, pain, pressure, heat, and cold. The subcutaneous fat layer beneath the dermis is several centimetres in thickness in certain parts of the body. It acts as an insulator against heat, cold, and as a shock absorber. The excess of body fat is accumulated in this region so that with aging, fat is absorbed and the skin shrinks unevenly causing

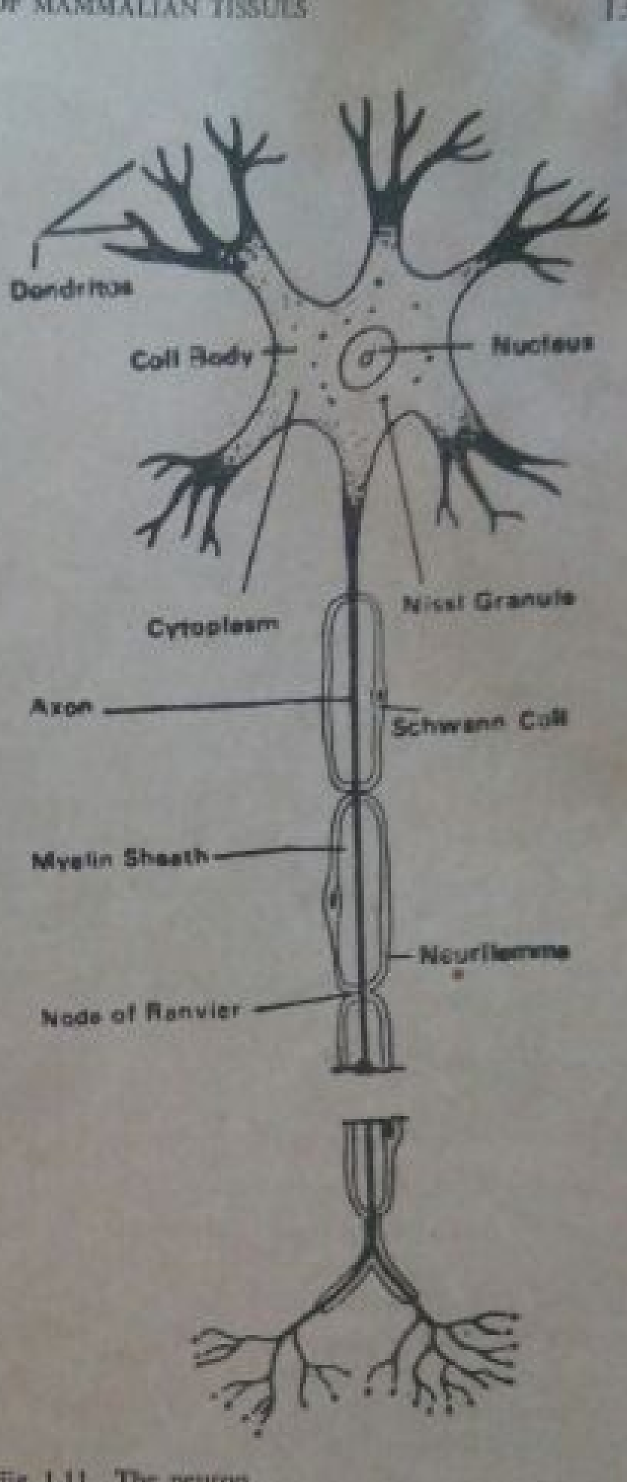


Fig. 1.11 The neuron

The skin has various types of epidermal and dermal modifications, in different vertebrates, e.g., mammals have *hair*, birds have *feathers*, reptiles and fishes possess *scales*, whereas the amphibian skin is naked but is kept moist with mucus secretion. Nails, hooves, antlers, horns, claws are examples of skin derivatives.

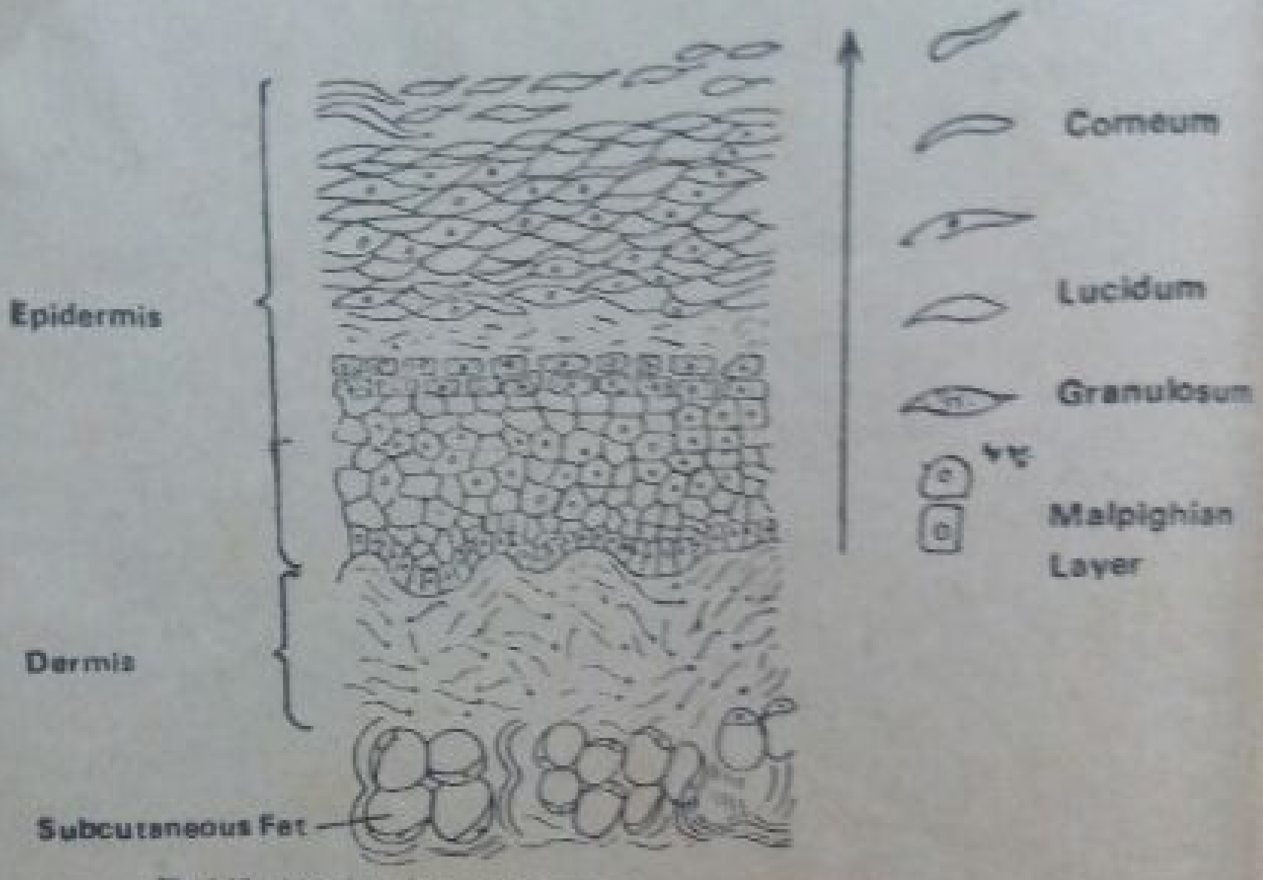


Fig. 1.12 A section of the skin showing the epidermis and the dermis

FUNCTIONS OF THE SKIN

1. *Protection*

Compact layers of the dead cells of the stratum corneum protect the layers of the living cells underneath from injury. The outer layers prevent the microbes from entering the body, and protect the internal tissues from the damaging effects of the strong sun rays. The oily secretions which are impermeable to water also safeguard the skin against the entry of several substances.

2. *Role in Metabolism*

The skin eliminates water, salts and other products in the form of *sweat*. The skin produces vitamin D (essential for the formation of bones and teeth) in the presence of sunlight.

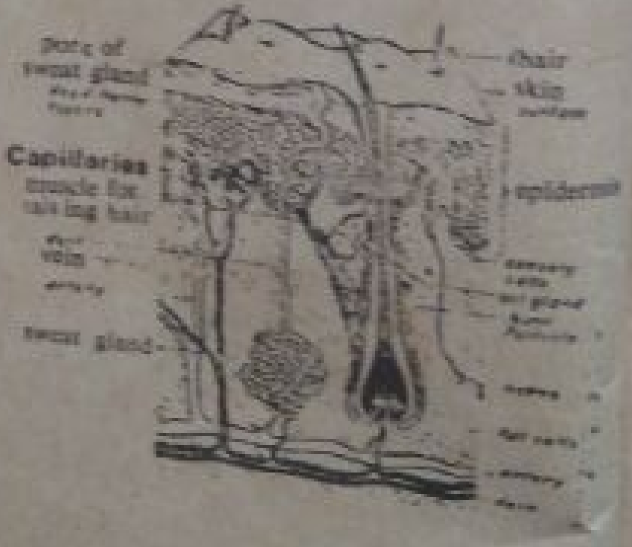


Fig. 1.13 A section of the skin showing hair, sweat glands,

3. *Sensory Function*

The skin helps perceive sensations of touch, pressure, pain, heat and cold.

4. *Thermo-regulatory Function*

The normal body temperature of man is 98.4°F or 37°C. This temperature of the body is maintained constant throughout the year in all kinds of weather. This is done by dilatation of the blood vessels of the skin and dissipation of heat from the surface of the skin by sweating, so that evaporation of sweat keeps the body cool in summer. In winter, the blood vessels constrict and very little sweat is produced so that the loss of heat through the skin is reduced.

5. *Accessory Respiratory Function*

In amphibia, the skin is kept moist by mucus and is richly supplied with blood and it functions as a site of *cutaneous respiration*.

EXERCISES

1. What is a tissue and an organ?
2. Where are stereocilia found?
3. What do you understand by stratified epithelium?
4. Enumerate the cell types of the connective tissue.
5. What are the main differences between cartilage and bone.
6. What are the functions of blood?
7. Is cardiac muscle involuntary or voluntary?
8. Where are modullated nerve fibres found?
9. Name some epidermal structures.
10. Describe the functions of skin.

CHAPTER 2

Digestive System

Organs of Digestion

The first organ of digestion is the *mouth cavity* with teeth which tear the food to pieces and chew (*masticate*) it. Dry food is mixed with *saliva* to moisten it. Saliva is produced by *salivary glands*. The gullet or *oesophagus* is a long tube which connects the mouth with the stomach. From the stomach, the food passes into the *duodenum*, then the small intestine or *ileum* and finally goes into the large intestine or colon. The undigested food passes to the rectum from where it is eliminated as *faeces* via the *anus* (Fig. 2.1). Besides the main digestive canal shown in the diagram, there are *glands*, e.g., the *liver*, *the pancreas*, and the *salivary glands* whose secretions help in the process of digestion.

Fig 2.1 The digestive system

HISTOLOGY OF THE DIGESTIVE ORGANS

The Stomach

The stomach has three parts, namely, the cardiac, fundus, pyloric (Fig. 2.2). Before

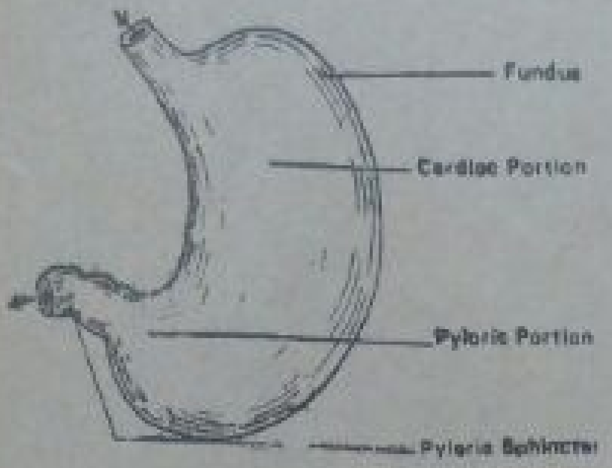


Fig. 2.2 Parts of the stomach.

studying the details of the histology of the stomach, familiarisation with a general plan of the make-up of the stomach and the intestine is necessary. In a transverse section examined under a microscope (Fig. 2.3), the outermost layer is the *serosa,* i.e., the connective tissue covering. The next layer is the *muscularis externa* which is made of smooth muscle fibres arranged longitudinally next to the serosa and then the circular muscle layer (Fig. 2.3). The *submucosa* is the adjacent layer which has loose collagen fibres, blood and lymphatic vessels and nerve fibres. The submucosa is thrown into several folds. The mucosa is the innermost region, forming the mucous membrane and is lined by a *simple columnar epithelium.* In between the submucosa and mucosa, there is a layer of a smooth muscle called *muscularis mucosae.* The submucosa and mucosa have several *glands* which produce secretions like the *gastric juice* and the intestinal juice.

Fig. 2.4 shows that the stomach walls have the same general pattern of layers as described above.

The mucosa is folded into ridges. The epithelium is *simple columnar* and has many

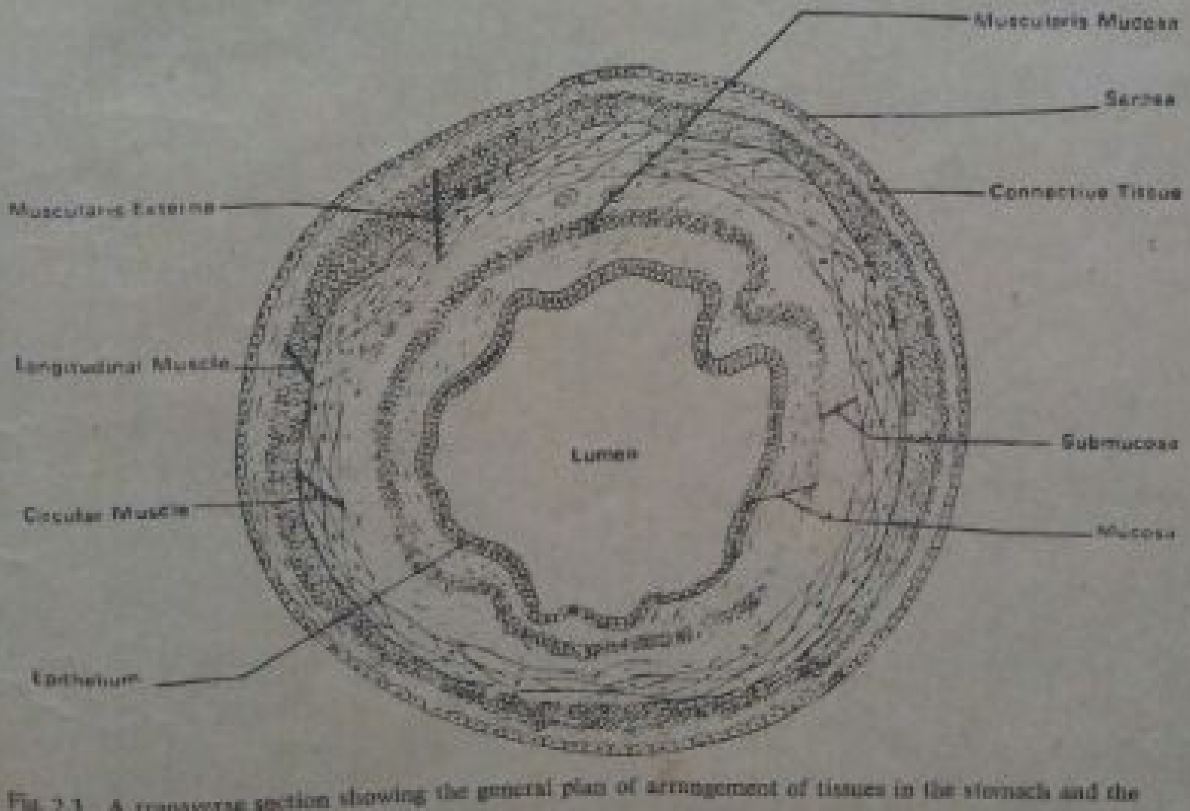


Fig. 2.3 A transverse section showing the general plan of arrangement of tissues in the stomach and the intestine

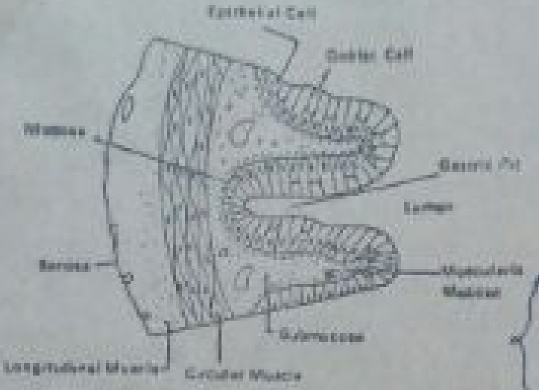


Fig. 2.4 A transverse section of a part of the stomach wall

mucus-producing goblet cells. The epithelial surface is divided by grooves into small irregular areas called *gastric areas* or *gastric pits*. The glands open into the gastric pits (Fig. 2.4). The gastric glands are supported by delicate connective tissue fibres, the *lamina propria*. The glands are: (i) gastric or *fundic glands* distributed in the mucosa, (ii) *pyloric glands*, and (iii) *cardiac glands* in the cardiac region of the stomach. There are three types of cells in these glands: (i) *chief cells* which produce digestive enzymes, (ii) *parietal cells* which produce dilute

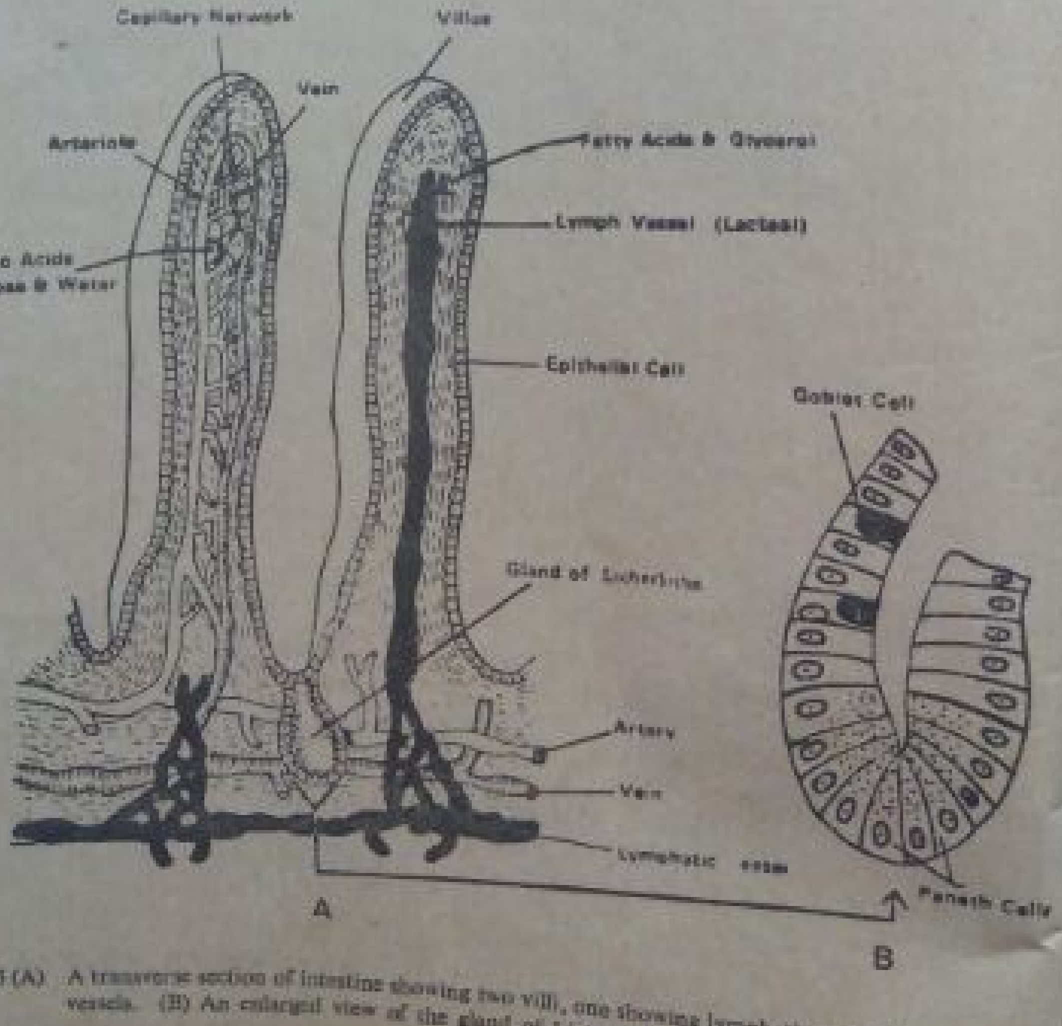


Fig. 2.5 (A) A transverse section of intestine showing two villi, one showing lymphatics and the other blood vessels. (B) An enlarged view of the gland of Lieberkuhn with the *Paneth* and

hydrochloric acid (HCl) and (iii) *mucous cells* which produce mucus.

The submucosa of the stomach is the dense connective tissue. The muscularis externa has a smooth muscle in *three* layers, namely, inner oblique, middle circular and outer longitudinal.

The Small Intestine

The basic structure of the small intestine is very similar to that of the stomach but the submucosa is folded to form finger-shaped villi (Fig. 2.5A). These villi help increase the surface areas of absorption of the intestine which is exposed to the digested food. Each villus is a projection lined by a single layer of a simple columnar epithelium which has absorbing cells and mucous cells known as *goblet cells*. The villus encloses a capillary loop and a small lymphatic vessel, the lacteal (Fig. 2.5A). Fat, which is broken down into fatty acids and glycerol in the intestine, passes into the lacteals→lymphatics→venous system. In between the villi, there are glandular pits, the crypts of Lieberkuhn (Fig. 2.5A). These are simple glands. The crypt has goblet cells and secretory cells called the *Paneth cells* (Fig. 2.5B) which produce digestive enzymes. The intestine also has isolated patches of lymphoid tissue called *Peyer's patches*.

The submucosa is the same as in the stomach. There are two muscle layers in the muscularis externa, an inner circular and an outer longitudinal. The serosa covers the muscles.

The Liver

The liver is the largest gland of the body. It produces *bile* and also has other important functions. The liver is made up of small units called *lobules*, with a *central vein* (Fig. 2.6). The liver cells or *hepatic cells* are arranged in cords or rows and in close contact with blood capillaries and blood spaces or *sinusoids*. The cells are angular or *polyhedral* with a centrally-placed nucleus (Fig. 2.7).

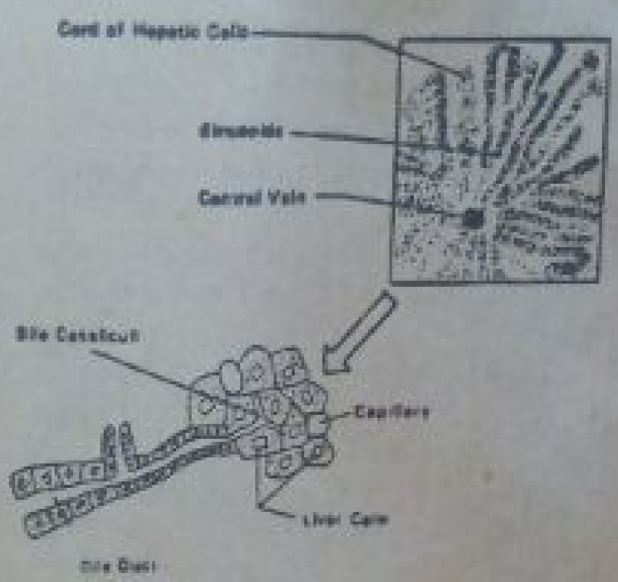


Fig. 2.6 A transverse section of the liver lobule with the central vein and cords of the hepatic cells, and a magnified view of a portion of the lobule showing the bile canaliculi and duct

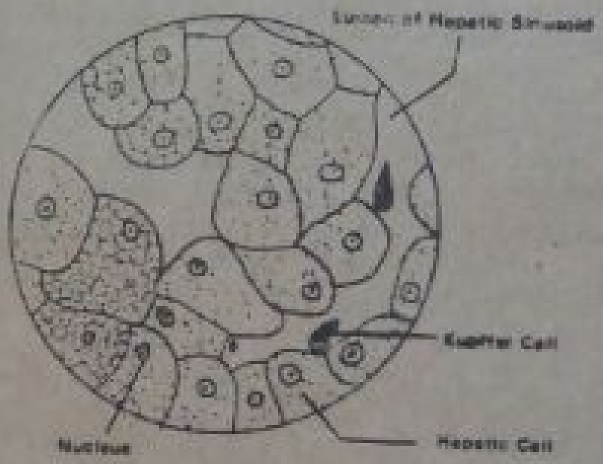


Fig. 2.7 A transverse section of a part of the liver magnified to show the hepatic cells and Kupffer cells

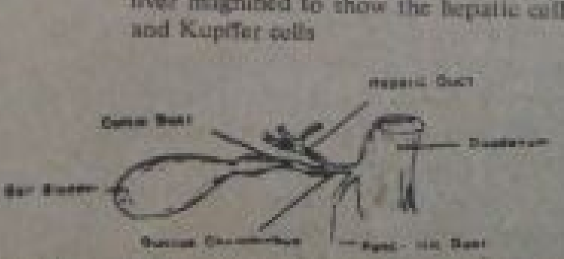


Fig. 2.8 The hepatic and pancreatic ducts opening into the duodenum

The Kupffer cells are phagocytic and with processes. They are anchored to the walls of the sinusoids. In between the hepatic cell cords, there are tiny spaces, the *bile canaliculi* (Fig. 2.6) which lead to *small bile ducts*. Smaller ducts later join to form the *hepatic duct* which joins into the *ductus choledochus* or Common bile duct emptying into the intestine (Fig. 2.8). But when there is no food in the intestine, the bile produced in the liver does not flow immediately into the intestine through these ducts, but remains stored in the *gall bladder*, by flowing to the latter through the *cystic duct* which connects the gall bladder with the common bile duct. When food enters the small intestine, the gall bladder contracts and the stored bile is expelled into the small intestine. Bile contains, bile salts which help in digestion and absorption of food. Besides, bile also contains bile pigments which are excretory waste products.

In normal, healthy individuals the plasma contains only a small quantity of a bile pigment *bilirubin* produced by the catabolism of haemoglobin of destroyed R.B.C; the major bulk of the bile pigment is normally removed from blood by the liver and secreted into the bile. But when the level of bile pigments increases in the plasma the skin, the white of the eye and the mucous membranes are stained yellow. This condition is called *Jaundice*. It is sometimes due to a disease of the liver caused by a virus.

The Pancreas

The pancreas is a compound gland. Its *exocrine part* secretes the pancreatic juice containing digestive enzymes which is drained into the intestine by the *pancreatic duct*. In addition, there are patches of cells called the *islets of Langerhans* (Fig. 2.9) which produce hormones *insulin* and *glucagon* (see Chapter 10 for details). This forms the *endocrine part* (ductless gland) as the hormones are liberated directly into the blood.

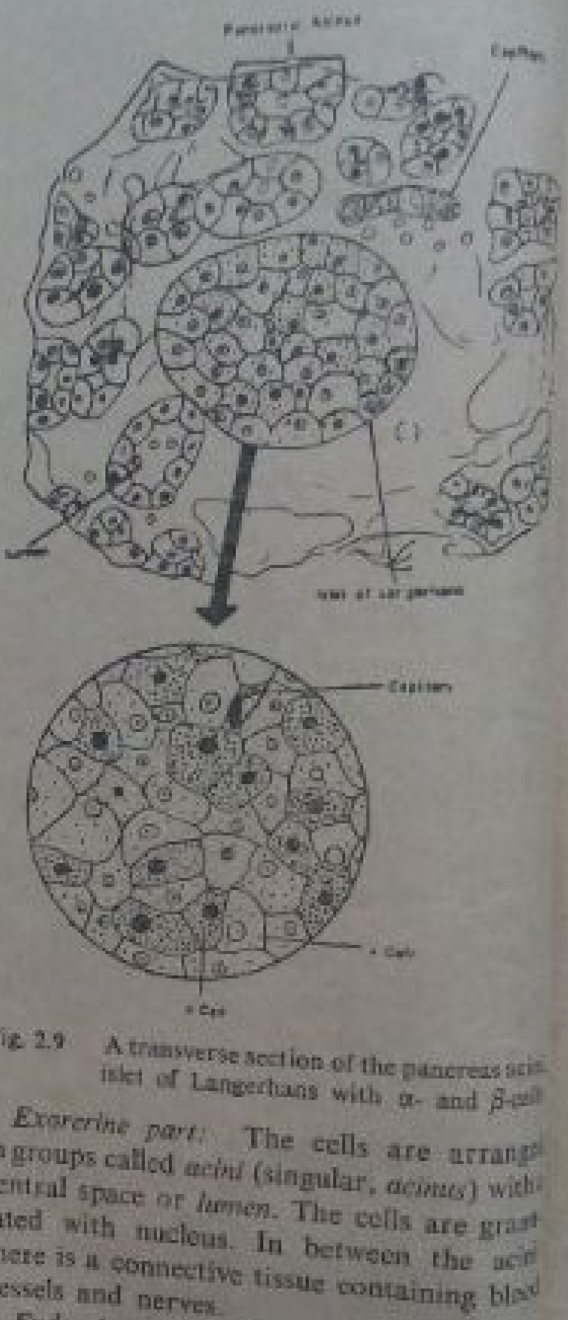


Fig. 2.9 A transverse section of the pancreas aci[…] islet of Langerhans with α- and β-c[…]

Exocrine part: The cells are arrang[…] in groups called *acini* (singular, *acinus*) with[…] central space or *lumen*. The cells are gra[…] lated with nucleus. In between the aci[…] there is a connective tissue containing blo[…] vessels and nerves.

Endocrine part: The islet of Langerha[…] has α-cells producing *glucagon* and β-ce[…] producing *insulin*. There may be many suc[…] islets in the pancreas. The endocrine function[…] of the α- and β-cells are described in Chap[…] ter 10.

Process of Digestion

Mammals are meat eaters (*carnivores*), o[…] plant eaters (*herbivores*) or mixed foo[…]

Fi

eaters (*omnivores*). The digestive organs and teeth are modified to suit the particular diet, e.g., in carnivores canine teeth are well developed to tear the meat. The herbivores have a longer small intestine than the carnivores to digest the plant material. Animals usually eat raw or uncooked food whereas human beings consume cooked food. Cooking makes the food soft and palatable. The food mainly consists of carbohydrates, proteins, and fats.

The major steps of digestion in vertebrates are shown in Fig. 2.10. Most food materials cannot be directly utilised by an animal. They have to be broken down to simpler substances by *enzymes*. For example:

Starch→Simple sugars (glucose, fructose, etc.)

Complex sugars→Simple sugars (sucrose, maltose, etc.)

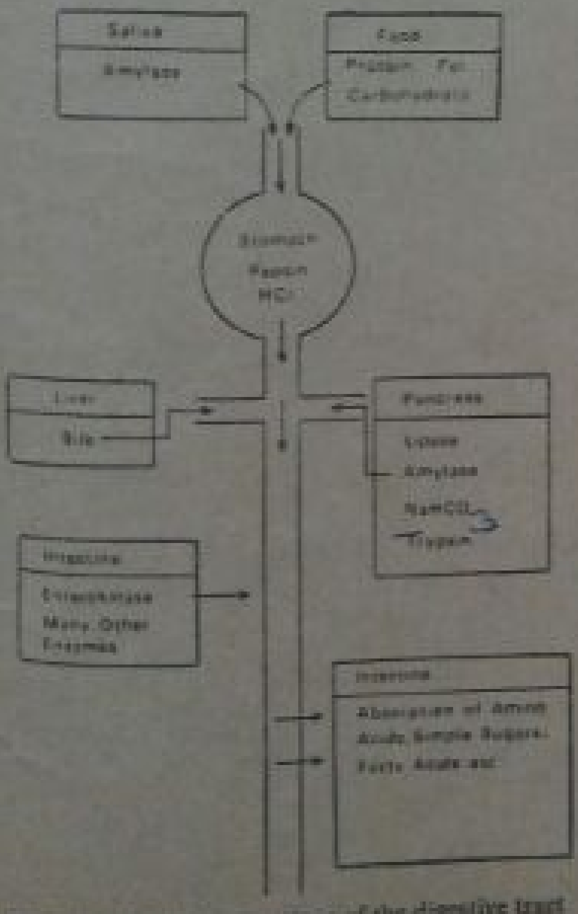


Fig. 2.10 The major secretions of the digestive tract

Fats→Fatty acids and glycerol

Proteins→Amino acids

In order to study the function of the different digestive enzymes, it is necessary that the main properties of enzymes be understood. Enzymes are catalysts and are proteinaceous in nature. All metabolic reactions in the body such as synthesis, breakdown and chemical transformations of substances are catalysed by enzymes. Enzymes are *specific* because any one enzyme acts on *only one* kind of substance called a *substrate*. An enzyme is named after the substrate it acts on or by the reaction it catalyses, e.g., maltase acts on maltose or malt sugar and *sucrase* acts on sucrose or cane sugar. However, there are some exceptions such as ptyalin, pepsin, trypsin etc. The action of an enzyme is influenced by certain factors, namely, temperature and pH (degree of acidity or alkalinity).

Temperature: The optimal temperature for an enzyme action is 37 °C while at 45 °C or above, the enzymes are inactivated, because being proteins, they are denatured (loss of structural and functional integrity).

pH (degree of acidity or alkalinity): The acidity increases with the number of hydrogen ions (H^+) and, likewise, alkalinity with hydroxyl ions (OH^-) in the medium. Neutral pH is 7, acidic solutions have pH below 7, e.g., the acidic gastric juice has pH 1.5, and alkaline solutions have pH above 7 (between 7 to 14), e.g., the intestinal juice.

DIGESTION IN THE MOUTH

The digestion of food starts in the mouth where the teeth *masticate* (chew) the food and break it into smaller particles so that a larger surface area is exposed for the action of enzymes. The food is also mixed with saliva which *lubricates* the food and aids in *swallowing* (deglutition) which is a reflex initiated by voluntary action of the tongue so that the food is propelled backward into the *pharynx*. A wave of involun-

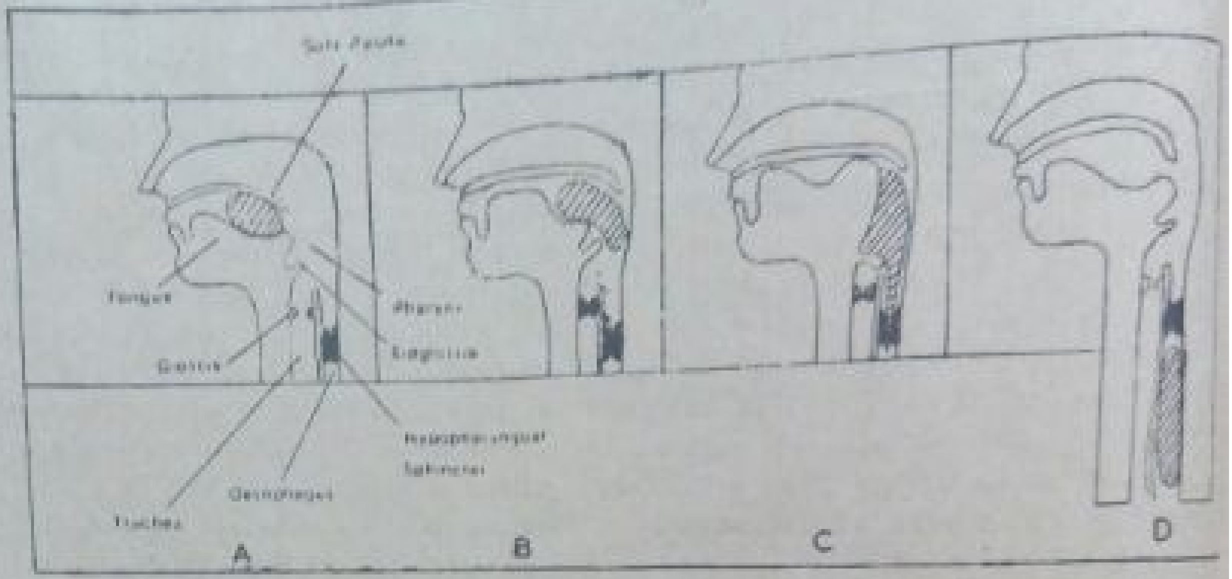


Fig. 2.11 Different stages of the swallowing of food

tary contractions of the pharyngeal muscles pushes the food materials into the oesophagus. Swallowing is difficult when the mouth is open. The closure of the *epiglottis* and *glottis* (the opening between the vocal cords) is part of the reflex response. This closure prevents the food from entering the trachea or wind-pipe (Fig. 2.11). In the mouth, the saliva secreted by the salivary glands (*parotid*, *submaxillary* and *sublingual*) acts on the starch (present in the food) and breaks it down by an enzyme, salivary *amylase* or *ptyalin* to complex sugars. The pH required for this enzyme is 6.7, i.e., almost neutral.

DIGESTION IN THE STOMACH

The food passes through the gullet into the stomach which serves as a reservoir for food and a site for digestion. The inner lining of the stomach has gastric glands which produce the protein-splitting (*proteolytic*) enzyme, pepsin and hydrochloric acid (0.5 per cent). The pH is between 1 and 2, (acidic) so that the digestion of starch which was initiated in the mouth, stops. The hydrochloric acid (HCl) inhibits all bacterial growth and the acidic pH facilitates the conversion of the precursor of pepsin, viz., *pepsinogen* into its active form, *pepsin*. Pepsin breaks proteins into pept and amino acids. The semiliquid food the stomach (*chyme*) passes into the duo num by contractions of the muscular w of the stomach called *peristalsis* which under the control of both the *vagus* (pa sympathetic) and sympathetic nerves. T passage of the chyme into the duode is also controlled by the opening and clos of the *pyloric sphincter*, i.e., a ring of smo muscle and connective tissue surround an opening between the pyloric region the stomach and the duodenum (Fig. 2. In the duodenum, the food mixes with bile and the pancreatic juice which poured by the bile and pancreatic du respectively (Fig. 2.8).

DIGESTION IN THE DUODENUM

The bile and the pancreatic juice cont sodium bicarbonate Na_2 HCO_3 which n tralies the HCl. The pancreatic juice a contains three enzymes: (i) The inact form of *trypsin* is *trypsinogen* which is co verted to the active *trypsin* by *enterokinase* the intestine; trypsin breaks down prote into *peptides* at an alkaline pH of 8.6, (ii) *pancreatic amylase* which converts carb hydrates (polysaccharides) into malt

(disaccharide), and (iii) *lipase* which splits fats into fatty acids and glycerol.

DIGESTION IN THE SMALL INTESTINE

As the food passes from the duodenum to the small intestine it is acted on by the intestinal juice (*succus entericus*) containing enzymes such as *erepsin*, *maltase*, *lactase*, *sucrase*, which break peptides into amino acids and disaccharides (complex sugars) like maltose, lactose and sucrose into glucose (monosaccharide or simple sugars), respectively. The pH requirement for the action of the intestinal and pancreatic enzymes is alkaline. The intestine pushes the food downward by peristalsis. The intestinal motility is under the nervous control. The sympathetic system acts as an inhibitor and slows down the intestinal motility whereas the parasympathetic system has a stimulatory effect.

Most of the mammals do not have any *cellulase* enzyme to digest *cellulose*. But in the herbivorous mammals, such as cows the intestine harbours microbes (*bacteria*) which digest the cellulose by fermentation.

ROLE OF THE BILE SALTS

The liver produces the bile which has no enzymes but has the bile salts which emulsify fats, activate lipase and help in the absorption of fats by combining with fat-soluble substances like cholesterol to form water-soluble complexes which can be more easily absorbed.

Thus, the digestion of all complex food materials is completed in the intestine. The action of different digestive enzymes is shown in Table 2.1.

NEUTRAL AND HORMONAL REGULATION OF DIGESTIVE JUICES

The secretion of digestive juices in the digestive tract or *alimentary canal* is regulated by both neural (by nerves) and hormonal (by hormones) mechanisms. The neural reflex secretions are produced in advance, whereas the secretion under the hormonal control follow subsequently. The neural regulation is spoken of a *conditioned reflex*. Secretions which are mediated by stimulation of the *vagus nerve* by talk, sight, smell, thought or presence of food in the tract, e.g., the thought of food 'makes the mouth water' due to salivary secretions in the mouth. Pavlov's experiments on animals demonstrated for the first time that the salivary secretion was conditioned by the above-mentioned factors.

The hormonal regulation of the secretion of digestive juices is brought by proteinaceous hormones of the digestive tract (Fig. 2.12).

TABLE 2.1

Digestive enzymes: their sources and effects

S. No.	Part of the digestive system	Source of enzymes	Enzymes	Substances acted upon	Product
1.	Mouth	Salivary glands	Amylase, Ptyalin	Starch	Complex sugars
2.	Stomach	Gastric glands	Pepsin	Proteins	Peptones and Amino acids
3.	Pancreas	Pancreatic juice	Trypsin Amylase Lipase	Proteins Carbohydrates Fats	Peptide Maltose or sugars Fatty acids and glycerol
4.	Small intestine	Intestinal glands	Erepsin Maltase Lactase Sucrase	Peptides Maltose Lactose Sucrose	Amino acids, Glucose and other sugars

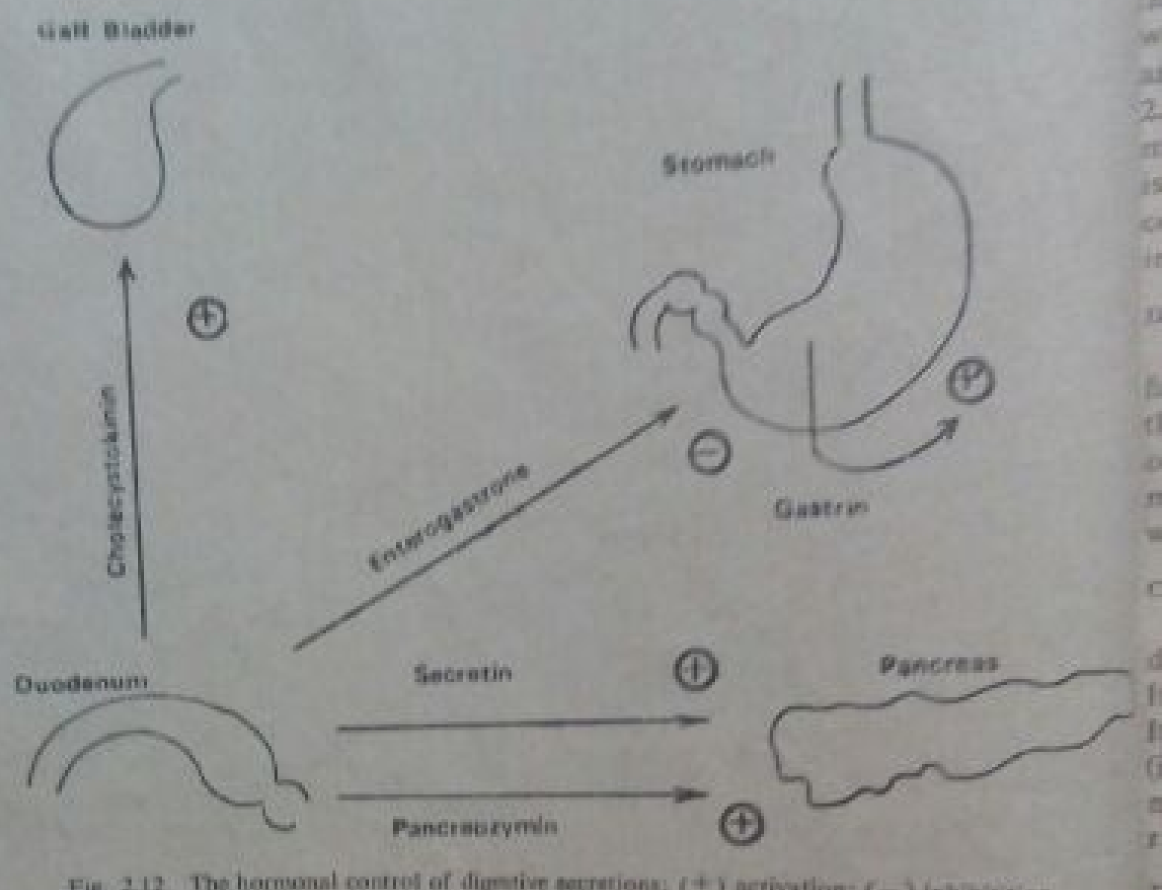


Fig. 2.12 The hormonal control of digestive secretions; (+) activation; (−) inhibition

They are: (i) *gastrin* which influences the secretion of digestive juices in the stomach. (ii) *secretin* from the duodenum which stimulates the flow of the pancreatic juice poor in enzymes. (iii) *pancreozymin* which helps produce the flow of pancreatic enzymes, (iv) *cholecystokinin* which influences the flow of the bile from the gall bladder, and (v) *enterogastrone* which released from the duodenum helps in the stoppage of gastric secretion. It has been shown now that pancreozymin and cholecystokinin are the same hormone.

VOMITING

Vomiting is the expulsion of the contents of the stomach and of the upper intestinal tract through the mouth. It is a complex reflex coordinated by the vomiting centre in the medulla of the brain and is generall preceded by increased salivation, sweati fa..er heart beat and a feeling of *nausea*.

ULCER

The high concentration of HCl and pr teolytic enzymes in the stomach do n harm the stomach epithelium as it is pr tected by a layer of *mucus* secreted by t goblet cells. The mucus is slightly alkal which neutralises the HCl. But in so people, these protective mechanisms a inadequate and lead to erosions of t gastric or duodenal mucosa. These erosio are *ulcers*.

INTESTINAL ABSORPTION

The digested food consists of simp sugars, amino acids, fatty acids and glycer The fatty acids and glycerol are absorbe

through the intestinal wall by lacteals, whereas sugars, amino acids, salts and water are passed into the blood circulation (Fig. 2.5A). The absorption of water takes place mainly in the *colon* (large intestine) which is also the site of vitamin B synthesis by certain bacteria. The vermiform appendix in man has no known function.

DEFECATION OR ELIMINATION

The undigested substances, e.g., plant fibres, dead bacteria, etc., are passed into the rectum from where they are thrown out of the body through the *anus*. This waste matter is called *faeces*. It has brown colour which is due to the presence of bile pigments.

CONSTIPATION

Constipation is a condition in which defecation occurs only at prolonged intervals. It is irregural or inadequate defecation. It is due to (i) decreased colon motility, (ii) a diet containing too little fluid, (iii) too much absorption of water by the colon, resulting in dry faecal matter.

DIARRHOEA

Diarrhoea is the opposite of constipation and is characterised by frequent defecation, usually of highly fluid faecal matter. A primary cause is greater intestinal motility with less time for absorption. Disease-producing bacteria often irritate the intestinal wall and increase its motility leading to diarrhoea.

Assimilation of Food

The body assimilates the digested food in the following manner: (i) The fatty acids and glycerol are reconverted into fats which are stored in the *adipose tissue*. The body can utilise this stored fat when there is a greater metabolic demand by splitting it again into fatty acids and glycerol by the action of lipase; (ii) The sugars are reconverted into the complex polysaccharide, glycogen in the liver. This stored glycogen is mobilised and utilising during conditions of stress. Excess amounts of fat in the body are also converted into carbohydrates by the process of *gluconeogenesis* and stored, (iii) The digested products of proteins, namely amino acids are utilised again for protein synthesis, as proteins are needed for building up the body tissues and enzymes.

METABOLISM OF THE MAJOR FOOD-STUFFS AND THEIR NUTRITIVE VALUE

The complete breakdown of the major food-stuffs like carbohydrates, fats and proteins by various chemical reactions is called *catabolism* which liberates energy in small, usable amounts. Energy can be stored in the body in the form of special energy rich phosphate compounds, mainly *adenosine triphosphate* (ATP), and in the form of proteins, fats and carbohydrates synthesised from simpler molecules. These substances are formed by several processes that utilise energy and are referred to as *anabolism*. The catabolic and anabolic processes together constitute the metabolism. The amount of energy liberated by the catabolism of food in the body appears as external work, heat and energy storage:

$$\text{Energy output} = \text{External work} + \text{Energy shortage} + \text{Heat}$$

ROLE OF THE LIVER IN METABOLISM

The liver is a vital organ in which certain important changes in proteins, carbohydrates and fats take place. The liver plays an important role in the whole process of metabolism in the following different ways; (i) It helps in carbohydrate metabolism by converting the excess of glucose into glycogen (*glycogenesis*) which is stored in the liver. When the level of glucose in the blood falls, the glycogen stored in the liver is reconverted into glucose which circulates in the blood. (ii) The excess of amino acids obtained by eating a very high protein diet is converted into carbohydrates in the liver. The process

BIOLOGY

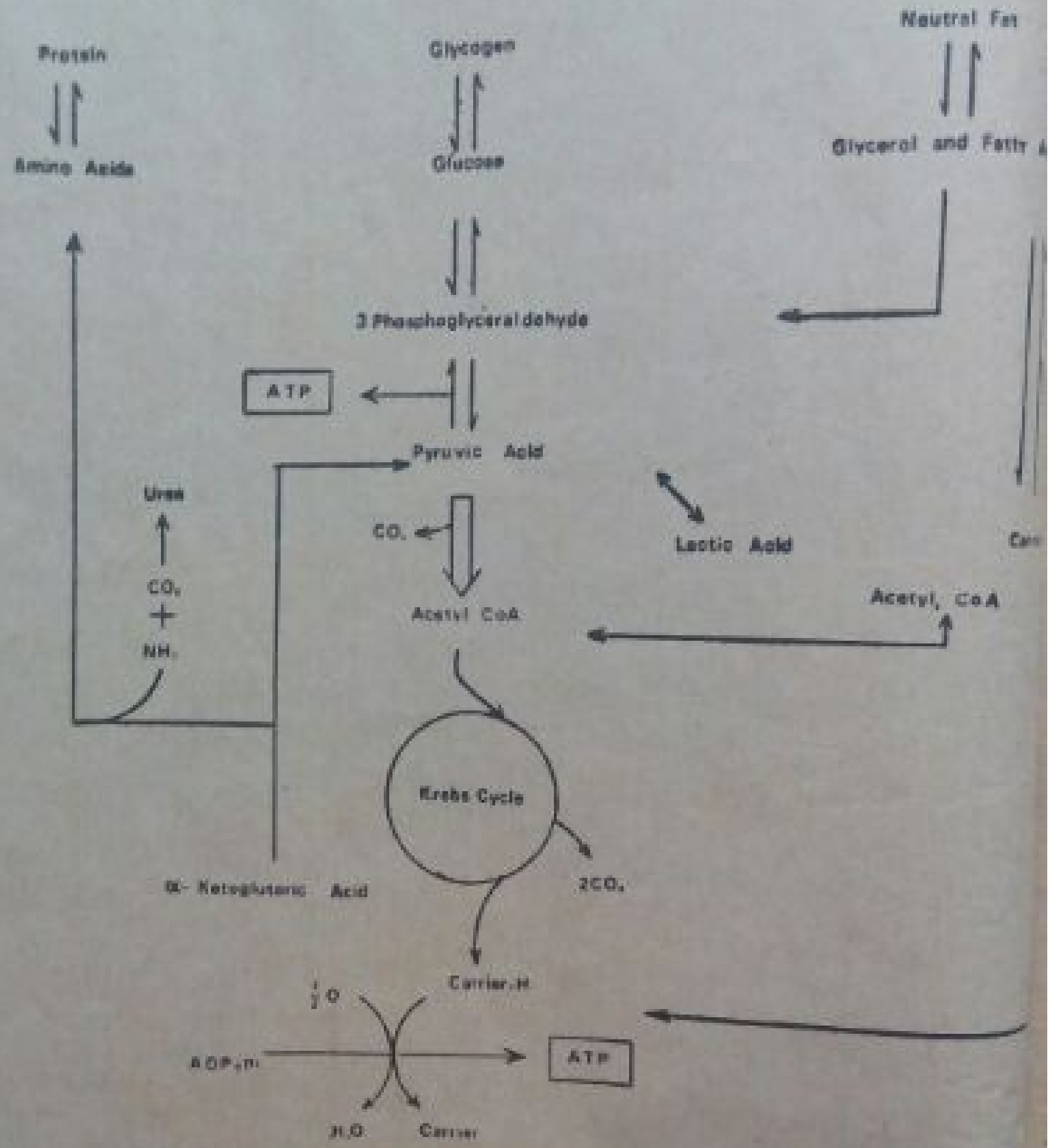


Fig. 2.13 Interrelationship between the metabolism of carbohydrates, fats and protei

is called *gluconeogenesis.* (iii) The conversion of carbohydrates into fats also takes place in the liver so that individuals on high carbohydrate diet tend to be *obese* (fat), since fat accumulates in their bodies. (iv) Metabolic processes yield substances which are harmful to the body. These are rendered harmless in the liver.

GENERAL PLAN OF METABOLISM OF THE DIGESTED FOOD

The end-products of the digestive p are amino acids, fatty acids, glycero sugars. These compounds are metab in the body as shown in Fig. 2.13. this common *metabolic pool* of intermed carbohydrates, fats and proteins c

thesised or else the intermediates undergo distinct metabolic transformations to finally yield energy. Thus, sugars undergo glycolysis to form pyruvic acid which subsequently enters the *Krebs cycle* to be completely oxidised; likewise, fatty acids undergo β-oxidation to give acetyl-COA which is then oxidized through the Krebs cycle. Similarly, amino acids are metabolised by deamination, (removal of the amino group), transamination (transfer of the amino group from one molecule to another), and interconvertions. On losing the amino group by deamination or transamination, the amino acid becomes a Keto acid which may be oxidised through Krebs cycle; the amino group removed from the amino acid as ammonia or otherwise is changed to urea by combination with CO_2. Krebs cycle is a final common pathway for catabolism of all intermediates, in which they are broken down to CO_2 and hydrogen atoms. The hydrogen atoms are oxidised to form water by a chain of *flavo-proteins* and *cytochromes* present in the *mitochondria* of the cells. Therefore, the mitochondria, wherein Krebs cycle and the hydrogen (electron) transport chain occur yielding energy, are referred to as the 'power house' of the cell. Each molecule of glucose metabolised via glycolysis and Krebs cycle yields a total of 38 ATP molecules. On the other hand, one molecule of a six-carbon fatty acid when metabolised the β-oxidation and Krebs cycle generates 44 molecules of ATP, compared to 38 molecules yielded by catabolism of a six-carbon sugar, glucose. The catabolism of amino acids does not yield a large amount of energy (ATP molecules), since some of it is utilised in deamination, transamination, transformation reactions, formation of urea, etc. (see the chapter on Excretion).

The *caloric value* of food can be assessed by the fact that one gram of carbohydrates yields 4.2 kilo-calorie (kcal). A calorie is the standard unit of heat energy and one kilo-calorie = 1000 calories. Similarly, one gram of fat yields 9.5 kcal and one gram of protein 4.3 kcal, respectively. So, fat has an energy value about twice that of protein or carbohydrates. The daily requirement of calories by a person depends largely on the living conditions, i.e., the kind of work done, the state of health, the bulk of the body, etc. If a person lies quietly without much motion, he expends one calorie/hour/kg of body weight. For a person of the average weight of 50-60 kg. a total of 1200-1400 calories/day are needed. The energy expended by an organism in this state is called *basal metabolic rate* (BMR). A person indulging in manual labour requires about 3000-3500 calories.

Nutritional Deficiency

For normal growth and development, one must take a balanced diet, i.e., a diet consisting of all classes of food in the right proportion. If normal nutrition is not available to a person, energy is obtained from the utilisation of the stored food materials of the body. Therefore, a person loses weight gradually.

VITAMINS OR ACCESSORY FOOD-STUFFS

In addition to the major food-stuffs, one needs other substances called *vitamins*. Vitamins are any organic dietary constituents which are necessary for life, health and growth. Vitamins are fat or water-soluble. The water-soluble ones are vitamin B-complex and vitamin C, whereas the fat-soluble ones are vitamins A, D, E and K. Most of them have important functions in the intermediary metabolism or the special metabolism of various organ systems. The deficiency of different vitamins causes different deficiency symptoms which are listed below.

Vitamin	Deficiency disease
1. A	Xerophthalmia and night blindness
2. B_1 (Thiamine)	Beri-beri
3. C (Ascorbic acid)	Scurvy
4. D (Calciferol)	Rickets
5. E (Tocopherol)	Muscular dystrophy and reproductive impair[illegible] laboratory animals
6. K	Haemorrhage

Vitamin A

The lack of vitamin A causes defective vision in dim light (*night blindness*). The mucous membranes, particularly of the eyes are weakened, resulting in dry cornea (*Xerophthalmia*). Liver, butter, egg-yolk, fish-liver oil are rich sources of vitamin A. The yellow substance of carrots is converted into vitamin A in the body.

Vitamin B

A group of nearly a dozen related vitamins is known to exist. This group is referred to as the *Vitamin B-Complex*. Some of the B-group vitamins help in the formation of certain enzymes. The lack of vitamin B_1 (thiamine) due to consumption of polished rice causes a disease *beri-beri* involving a general weakening of muscles and paralysis. The vitamin B-complex is found in the seed of grains, in nuts, fruits of leguminous plants, in cabbages, carrots, eggs, liver, milk, green vegetables and yeast.

Vitamin C

Vitamin C is also called *ascorbic acid* whose deficiency results in *scurvy*. The disease is characterised by aching and swollen joints, bleeding gums, skin bruises and blackened lips.

Vitamin C participates in several oxidation-reduction reactions in the body and it is presumed that it reduces virulence of some viral diseases.

Vitamin C is found abundantly in citrus fruits like orange, lime, lemon, tomato, and leafy vegetables. The vitamin is heat labile and is destroyed by cooking. Therefo[re] fruits and vegetables must be included [in] diet as the human body is not capa[ble of] synthesising ascorbic acid.

Vitamin D

Vitamin D is produced by the skin [in] presence of sunlight. It is essential for [bone] and teeth formation in children. The [lack] of vitamin D in children leads to *rick[ets]* which bones of the legs become bow-sh[aped]. In adults the loss of bone calcium and [phos]phorus occurs (*osteomalacia*) which in[duces] frequent fractures.

Liver, egg and shark-liver oil are [rich] sources of vitamin D.

Vitamin E

The lack of vitamin E causes *mu[scular] dystrophy* and impairment of reprod[uctive] functions in laboratory animals. It is f[ound] in leafy vegetables, milk and butter.

Vitamin K

Vitamin K is essential for normal cl[otting] of blood. Its deficiency causes *haemorrh[age]*. It is present in green vegetables, soy[bean] oil, tomatoes and is synthesised by ba[cteria] in the gut.

The body also requires some major m[ineral] elements, such as calcium and phosp[horus] for bone formation; iron for haemog[lobin] formation; iodine for the formatio[n of] thyroxin hormone in the thyroid g[land]. Sodium and potassium are also ess[ential] major elements needed by the body. O[thers] like cobalt, zinc, magnesium, manga[nese]

side are required in very small quantities are called trace elements. The symptoms produced due to the deficiency of certain elements are given below:

Major elements	*Deficiency symptom*
Copper; Iron	Anaemia
Iodine	Goitre
Calcium	Bone abnormalities
Phosphorus	

EXERCISES

1. What is the action of salivary amylase?
2. What is a superior — a strictly vegetarian or mixed — diet? Why?
3. What is the advantage of having villi in the intestinal wall?
4. The wall of the alimentary canal has a thick layer of muscles. What is their function?
5. What is the function of HCl in the stomach?
6. What is the role of the liver in digestion?
7. What are lacteals? Where are they present?
8. How is food absorbed?
9. What is conditioned reflex? How is the secretion of digestive juices controlled?
10. Which diseases are caused by the deficiency of iron; vitamin C and vitamin A?

CHAPTER 3

Respiratory System

THE oxidation of food substances in the body to release energy is called respiration. The process includes exchange of gases, oxygen and carbon dioxide between the body and the outside environment. The organs needed for this gaseous exchange form the *respiratory system*.

The various groups of chordates have different organs of respiration. Fishes have gills and the other chordates from frogs to mammals have a pair of lungs. Frogs can also respire through their skin which is moist.

Organs of Respiration in a Mammal

In a mammal, the lungs are large and occupy the major part of the chest cavity or thoracic cavity which is bounded on the sides by ribs and below by the muscular *diaphragm* (Fig. 3.1). The outer surface of the lung is covered by a pleural membrane. The lung has branching air passages and folded walls and is made up of many *alveoli* (Fig. 3.2). Air enters the body through the nose

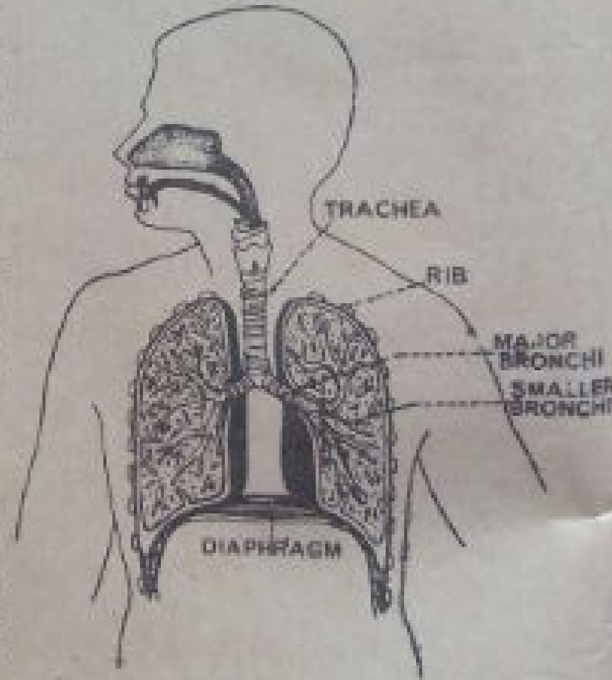
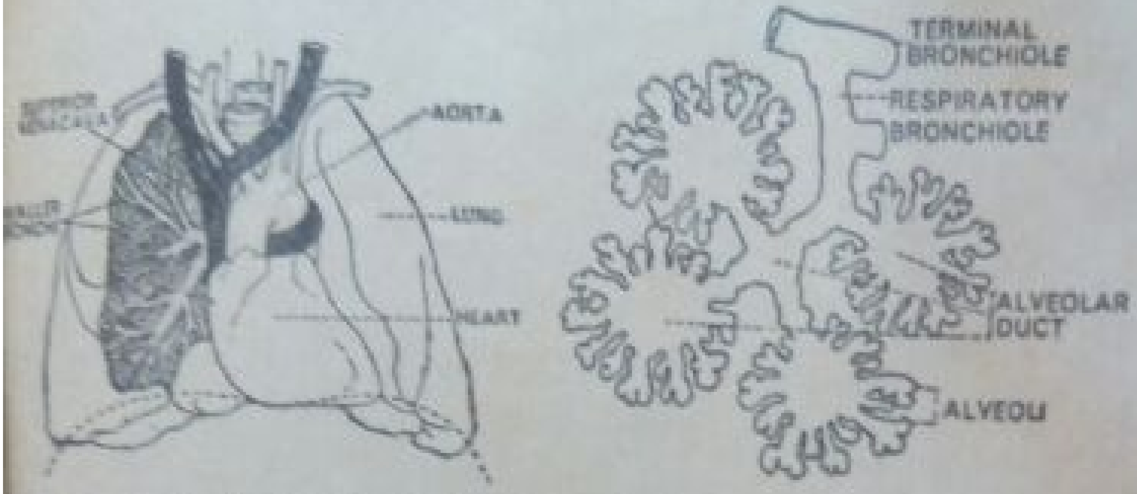


Fig. 3.1 Respiratory organs of man

and the pharynx and then goes into the windpipe or *trachea*. The opening into the



3.2 The gross structure of the lungs showing the *alveoli* and the magnified view of a part of the lungs.

...pipe is a narrow slit, the *glottis*, through ...ch the air passes into the trachea via the ...nx (voice box). Since the pharynx is the ...mon passage for both food and air, a ...-like cartilaginous organ called *epiglottis* ...s the opening of the larynx during ...llowing (see Chapter 2). This prevents the ...age of food in the trachea which other... ...e causes *chocking* and coughing.

...e trachea is a tube supported by carti-...nous rings. At its lower end, it divides ... major *bronchi* (singular, *bronchus*). The ...nchi divide and subdivide so that each ...al bronchiole terminates in an *alveolus* ...ir sac of the lungs. The passage of air ...s follows: nose→pharynx→trachea→ ...nchi→bronchioles→alveolus of the lungs.

... LUNGS

...ere is a pair of lungs. In a mammal, ...right lung is larger than the left lung ...t their lower surfaces are concave to ...ommodate the *diaphragm* which divides ...e body cavity into the *thoracic* and *abdo-* ...*al* regions. The lungs are enveloped by a ...ble-layered membrane called the *pleura*. ...e delicate lungs are well protected in the bony case formed by the breast bone on the front (*ventral*) side, the ribs on the sides (*lateral*) and the vertebral column on the back (*dorsal*) side.

HISTOLOGY OF THE LUNGS

Each *major bronchus* from the trachea enters the root of a lung and divides and subdivides to give progressively smaller *bronchii* and then, still smaller *bronchioles*. The small *terminal bronchioles* branch into *respiratory bronchioles* which branch again into *alveolar ducts* ending ultimately into *alveoli*.

The rings of cartilage in the walls of the trachea and bronchi make them elastic and prevent them from collapsing and air is allowed to pass freely.

The respiratory tract is lined internally with the mucous membrane which is kept moist. Any small particles of dust or micro-bes which pass in with the inhaled air are caught and held in the moist surface of the mucous membrane so that the air passing through the respiratory tract is almost free of suspended particles. The ciliated cells of

the trachea and bronchi push up these particles and help in preventing them from reaching the air passages of the lungs.

The epithelium in the conducting bronchioles (upto the terminal bronchioles) is pseudostratified and columnar but decreases in height as the tubules become smaller in diameter. In the terminal bronchiole, the epithelium is a single layer of columnar or cuboidal cells which still have cilia. The mucous cells are few in number and are absent in the terminal bronchioles as the accumulation of mucus might occlude the tubules. Elastic and recticular fibres and muscle are present but cartilage is absent.

The thin-walled alveoli help in the interchange of gas between blood and the air. The epithelium is thin and made up of a simple squamous, non-ciliated epithelium (Fig. 3.2, 3.3).

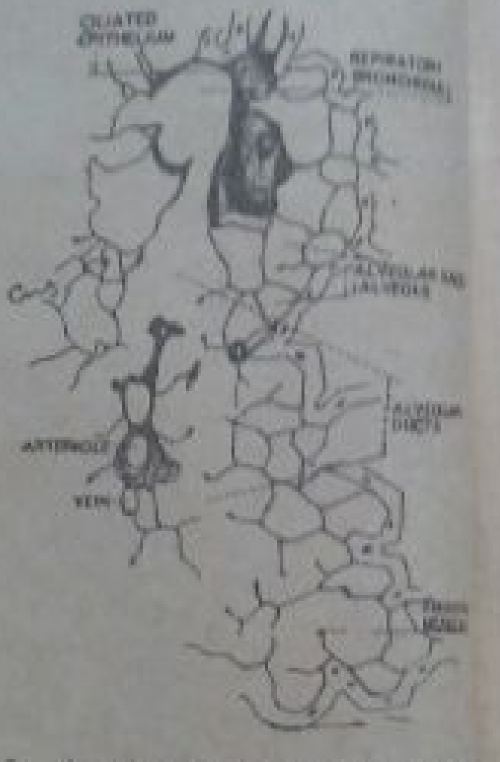


Fig. 3.3 A transverse section of a part of the l showing the *alveolar duct*, the *pulm* (lung) *alveoli* and the thin epithel

Mechanism of Respiration

The process of respiration is divisible into *inspiration* or breathing in of the oxygen rich air and *expiration* or breathing out of the air loaded with carbon dioxide.

INSPIRATION

The intercostal muscles in between the ribs pull them upward and outward. The muscular *diaphragm* also contracts and flattens, so the pleural cavity is enlarged, i.e., the chest expands. The lungs are, thus, enlarged creating a partial vacuum due to which the outside air rushes in through the trachea (Fig. 3.4).

EXPIRATION

The ribs are lowered by the intercostal muscles and the diaphragm become arched (raised), so that the pleural cavity becomes compressed (Fig. 3.4), forcing the air out of the lungs via the trachea through the nose. Some air remains in the lungs after the maximum forced exhalation which is referred to as the *residual volume*. The gre amount of air that can be expired af maximal inspiratory effort is measured a index of pulmonary (lung) function. Th called as the *vital capacity*. On the other ha the amount of air that moves in with e inspiration (or the amount that moves with each expiration) is called the *ti volume*.

GAS EXCHANGE IN THE LUNGS

The gas exchange involves the follow steps :

(i) *Exchange of air between the atmosph (external environment) and alveoli*. Th process includes the movement of air in a out of the lungs and the distribution of within the lungs. This process is *ventila* of the lungs. (ii) *Exchange of oxygen* (*and carbon dioxide* (CO_2) *between alve air and lung capillaries by diffusion*. T blood coming from the heart has low O_2 high CO_2 content.

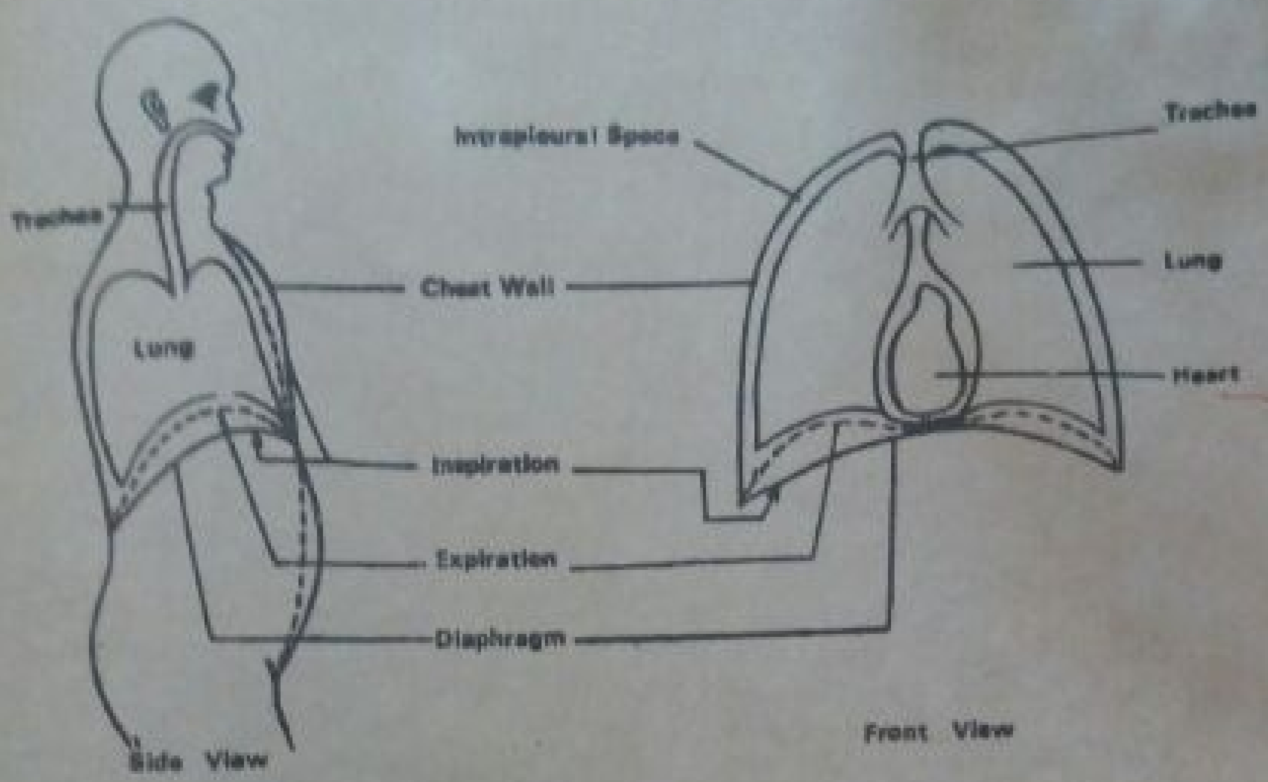


Fig. 3.4 The position of the chest wall and the diaphragm during *inspiration* and *expiration*

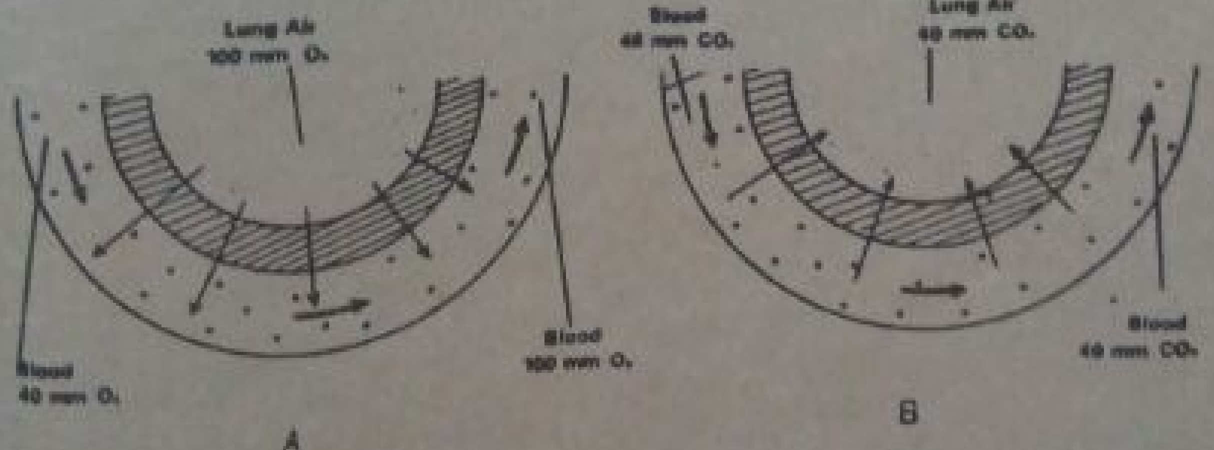
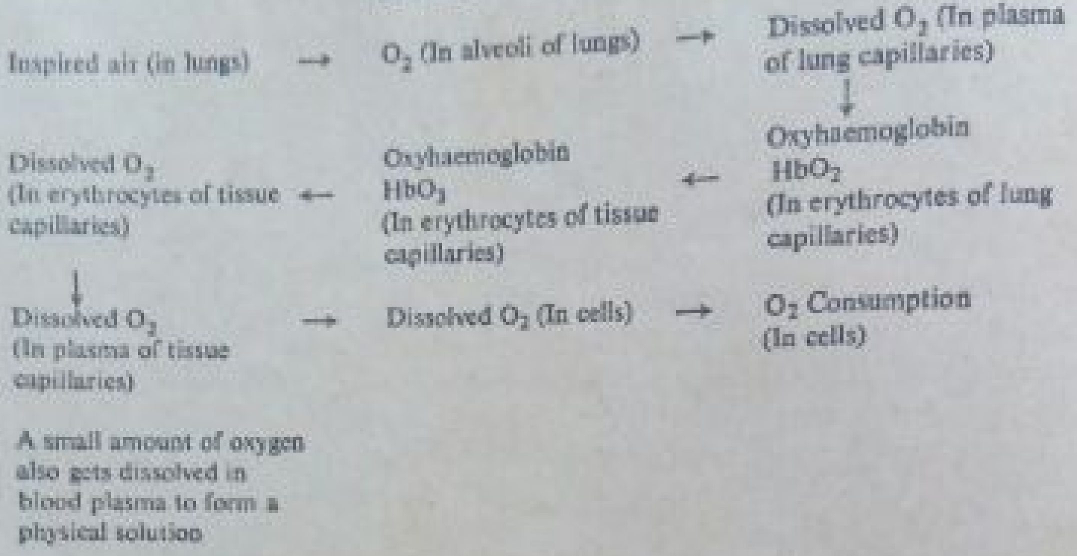


Fig. 3.5 The exchange of gases between the lung and blood

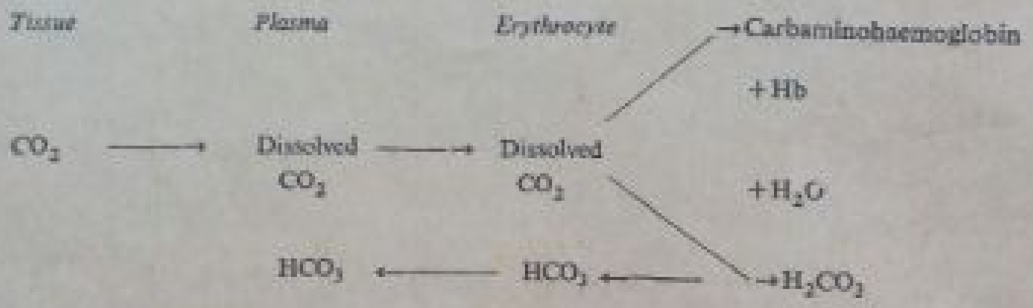
the blood and CO_2 leaves it. This is a simple process of gaseous diffusion across the moist respiratory epithelium (Fig. 3.5A, B). When the blood which is low in O_2 reaches the lungs, the haemoglobin of the red blood corpuscles becomes loaded up with O_2, to form oxyhaemoglobin. A small amount of O_2 also gets dissolved in blood plasma to form

Summary of Oxygen transport

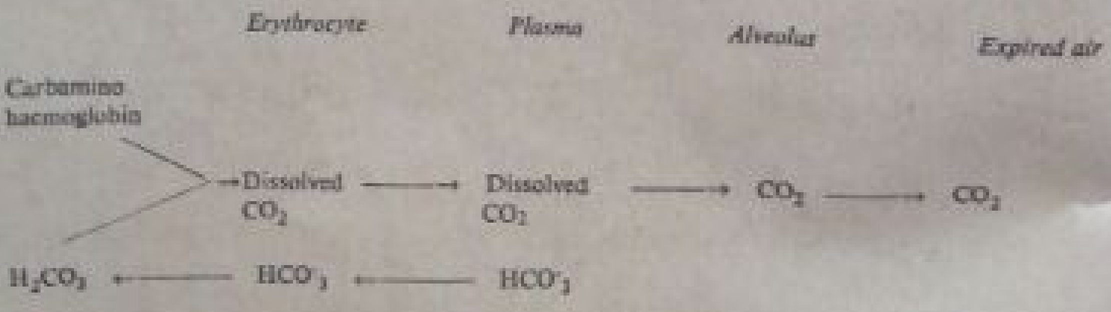


Summary of CO_2 transport

a. in tissue capillaries



b. in lung capillaries



a physical solution. (iii) *Exchange of O_2 and CO_2 between the blood and tissues.* This exchange also takes place by diffusion across the capillary wall. Oxyhaemoglobin dissociates to liberate O_2 which diffuses out into the tissues. CO_2, on the other hand, diffuses into the blood from the tissues. A small amount of CO_2 gets dissolved in the blood plasma to form a physical solution. A greater amount of CO_2 combines with haemoglobin

to form *carbaminohaemoglobin* inside the RBC and is transported to the lungs in that form. A still greater amount of CO_2 reacts with water to form carbonic acid, particularly inside RBC; bicarbonates formed from this carbonic acid are transported in the plasma and RBC. From these complexes, CO_2 is given out in the lungs when blood is oxygenated there (Fig. 3.5A, B). A diagrammatic description of the process is given above.

Besides haemoglobin, there are other O_2 transporting pigments in animals. Vertebrates have haemoglobin, but other animals possess pigments like *haemocyanin* and *haemerythrin*.

REGULATION OF RESPIRATION

The regulatory centre for respiration lies in the medulla of the brain and is sensitive to the changes in the arterial concentration of CO_2. A decrease or increase in the concentration of CO_2 in the arterial blood causes the slowing or acceleration, respectively, of the rate and depth of breathing. During holding of the breath by closing the nose with fingers, CO_2 build up so that when the nose opens again, the breathing becomes accelerated.

Hypoxia or a condition of oxygen shortage may be produced in the body due to, for example, a lack of O_2 in the inspired air. This type of hypoxia, known as arterial hypoxia, is the reason for the *mountain sickness* in persons climbing to high altitudes without the aid of oxygen cylinders. Breathlessness, headache, bluish hue of skin and mucous membranes and moderate to severe nervous symptoms may be seen in mountain sickness.

In *anaemia*, the amount of haemoglobin in the blood is lowered due to a fall in the RBC count below 4 million/mm^3 in females and 4.5 million/mm^3 in males; in case of carbon monoxide (CO) poisoning, some haemoglobin gets irreversibly bound up with CO due to its higher affinity for the latter than for O_2 and the amount of haemoglobin available for carrying O_2 in the blood is correspondingly reduced. In such cases, hypoxia may result from the reduced O_2 carrying capacity of the blood (*anaemic hypoxia*).

Hypoxia may also result when the capacity of the tissues to use the oxygen supplied to them is lost (*histotoxic hypoxia*). This type of hypoxia is produced by cyanide poisoning because cyanides block the electron transport chain in tissue cells.

Excess of CO_2 with a simultaneous lack of O_2 produces *asphyxia* which is the cause of respiratory and circulatory failures and death in case of suffocation.

SOME RESPIRATORY DISORDERS

Pneumonia

The lymph and mucus accumulate in the alveoli and bronchioles due to bacterial infections.

Emphysema

When the gas exchange area of the lungs is reduced by breaking up of the walls separating the alveoli, it is called emphysema.

Tuberculosis

Tuberculosis is caused by a type of bacteria which affects the lungs. The bacteria can spread and cause infection in another person through the *sputum* of the infected person. Sputum is the mucus expelled from the trachea via the mouth. Sputum contains the trapped dust particles which were not filtered out by the nose. Tuberculosis can be curbed by the *BCG* (Bacillo-Calmette Guérin) *vaccine*.

Cough

Excessive smoking is known to cause irritation of the throat and respiratory passages leading to *cough*. Prolonged smoking impairs the efficient functioning of various organs and makes them vulnerable

diseases. Cigarettes, bidis, cigars, etc., contain *tobacco* which contains *nicotine*. Nicotine has harmful effects on the nervous system, blood vessels, digestive organs and lungs. Heavy smoking is also known to cause cancer of the lungs.

EXERCISES

1. Breathing through the nose is said to be healthier than through the mouth. Why?
2. What is the difference between breathing and respiration? What causes coughing?
3. Why does it become difficult to breathe at high altitudes?
4. What are the organs of respiration in a mammal?
5. What are the steps of gaseous exchange in the lungs?
6. What do you understand by residual volume, tidal volume and vital capacity?
7. What is the role of haemoglobin in respiration?
8. When haemoglobin content is less, which disease occurs?
9. What happens in the alveoli?
10. What is pneumonia? Why is smoking bad for health?

CHAPTER 4

Circulatory System

THE body and tissue fluids of multicellular animals perform those important functions which in unicellular animals are carried out through the medium of their watery environment. Thus, in amoeba oxygen is received by diffusion from the surrounding water and carbon dioxide similarly diffuses out through the cell membrane. The processes of nutrition and excretion are accomplished in an equally primitive manner. The other requirements of the unicellular organism, such as the maintenance of an optimum temperature and the proper degree of moisture, are dependent upon the immediate environment. In most multicellular animals, there is a closed circulatory system of canals, the *blood vessels*, which transport the fluid, blood to all parts of the body. Blood fulfils all the functions such as those of nutrition, respiration, excretion, maintenance of moisture and body temperature, protection of the body against foreign matter, etc. The forceful pumping of blood into the vessels is done by the muscular *heart*.

Composition of Blood

Blood is a fluid tissue consisting of the liquid *plasma* in which float the *blood corpuscles* or cells.

PLASMA

Plasma is a straw-coloured fluid and has 90-92 per cent water and 8-10 per cent solids. The solid part consists of the following constituents: (i) *Proteins* (7 per cent) such as *serum albumin*, *globulin* (which includes antibodies), and *fibrinogen* (which helps in blood clotting). The plasma from which the fibrinogen has been removed by clotting is called *serum*. (ii) *Inorganic constituents* are 0.9 per cent sodium, calcium, potassium, magnesium, phosphorus, etc. (iii) *Non-protein organic substances* are urea, uric acid, xanthine, creatine, creatinine and ammonia

which are excretory products, and other metabolites like neutral fats, phospholipids, cholesterol and glucose. (iv) *Respiratory gases*, e.g., oxygen and carbon dioxide. (v) Hormones, enzymes and antibodies.

BLOOD CELLS

There are three major types of blood cells. They are:

(i) Red blood corpuscles or erythrocytes (RBC)

(ii) White blood corpuscles or leucocytes (WBC)

(iii) Platelets or thrombocytes.

(i) *Erythrocytes*

The red blood corpuscles or erythrocytes (erythro = red; cytes = cell) of man and other mammals are circular disc-shaped cells possessing no nucleus in the mature stage (see Chapter 1). These cells appear as biconcave discs and carry an iron-containing pigment called *haemoglobin* which has the capacity to carry oxygen and carbon dioxide. Thus, the red blood corpuscles carry oxygen from the lungs to all parts of the body and also some CO_2 from the body cells to the lungs. In normal healthy individuals, the number of RBC per cubic millimetre of blood ranges between 4.5 to 5 million in females and between 5 to 5.5 in males. This red cell count can be done by an instrument called the *haemocytometer*. The red cell count decreases in *anaemia* in which the haemoglobin concentration is below normal. Anaemia can occur due to blood loss or destruction of blood cells or due to defective blood formation as a result of iron, protein and vitamin deficiencies and due to toxic substances (ingested, inhaled or produced during the disease) which depress the function of the bone marrow. On the other hand, the red blood cell count increases (a) during muscular exercise, (b) at high altitudes due to low oxygen tension of the air (*polycythemia*), and (c) as a result of a rise in environmental temperature.

(ii) *Leucocytes*

The leucocytes or white blood corpuscles are colourless due to the absence of haemoglobin, but unlike the red cells, they possess a nucleus (see Fig. 1.9). They are larger than the RBC. The leucocytes are able to move about like an amoeba and pass through the capillary walls into the lymph or tissue fluid. They are fewer than the RBC and the total count is between 6,000 and 10,000 per cubic millimetre of blood. They are produced in the bone marrow and in the lymph glands. Their main function is to destroy harmful bacteria and to remove some other foreign materials from the tissues and blood by ingesting them (*phagocytosis*). When the body is infected with bacteria, the WBC increases in the number. When their number increases ceaselessly as in the bone marrow cancer, the disease is called *leukemia*.

There are two main types of leucocytes: (i) those without granules in the cytoplasm and with an unlobed nucleus, called *agranular leucocytes*, and (ii) those with granules in the cytoplasm and a nucleus having two or more lobes, called *granular leucocytes*.

Agranular leucocytes: These are mainly of two types: *lymphocytes* and *monocytes*. The monocytes are large and have a kidney-shaped nucleus, whereas the nucleus of the lymphocytes is generally round and has little cytoplasm (Fig. 1.9).

Granular leucocytes: Three main types of these leucocytes are found in blood, viz., *eosinophils*, *basophils* and *neutrophils*. The cytoplasm of eosinophils is packed with course granules which stain with acid dyes (e.g., eosin) and the nucleus has two lobes. The granules of basophils stain with basic dyes (e.g., methylene blue) and have a bilobed nucleus. The neutrophils have fine granules which stain with neutral dyes or with a mixture of acid and basic dyes and

possess a multilobed nucleus (see Chapter 1, Fig. 1.9).

(iii) *Blood Platelets*

Blood platelets or *thrombocytes* are very small irregular bodies, even smaller than the RBC. They do not possess a nucleus but their cytoplasm contains distinct granules. Their origin is not known with certainty. The most widely held opinion is that they are fragments of protoplasm broken or separated in some way from giant cells (*megakaryocytes*) found in the red bone marrow. The platelets number about 250,000 per cubic mm. They play an important part in the coagulation of blood.

Functions of Blood

The important functions of the blood in animals are :

(i) *Transport* of oxygen, carbon dioxide, nutrients and metabolites, waste products, hormones.

(ii) *Protection* from (a) harmful bacteria, protozoa, viruses and other foreign substances. (b) protection from the excessive loss of blood by blood coagulation.

(iii) *Regulation* of temperature in warm blooded animals (birds and mammals), of water content of the tissues and of the pH.

Some of these functions have been discussed in the chapter on Respiratory System (transport of gases and body temperature regulation) and transport of nutrients in the chapter on Digestive System. The others are considered here :

(a) *Transport of Waste Products*

Of the metabolic waste products, the transport of CO_2 in the blood is discussed in the chapter on Respiratory System.

The other excretory products like ammonia urea, or uric acid are transported to the kidneys for excretion (see the chapter on Excretory System).

(b) *Transport of Metabolic Products and Hormones*

Blood transports hormones and various other substances from the organs of their origin to other parts of the body. Hormones, which control the various metabolic processes (see Chapter 9) are liberated into the blood stream and then transported to different organs.

(c) *Maintenance of Water Content of the Tissues*

Although blood itself is contained within definite channels, the arteries, veins and capillaries (Fig. 4.6), a constant interchange of the fluid takes place across the walls of the capillaries.

(d) *Protection from Invading Organisms and Foreign Substances*

The leucocytes, particularly neutrophils and monocytes engulf bacteria, protozoa, etc. by phagocytosis and destroy them. Lymphocytes participate in forming antibodies which react with and destroy invading organisms and their toxins (see Immunity also).

(e) *Blood Coagulation*

When a finger is cut with a blade, blood flows out of the wound. After a few minutes, the blood flow stops as it thickens and forms a *clot*. This process is called *coagulation* or *clotting of blood* and is a protective function of the blood against its excessive loss from a wound. The different events of blood coagulation are shown in Fig. 4.1.

Plasma contains a protein called *prothrombin*. In the presence of *calcium ions* of plasma and an enzyme *thromboplastin* from the damaged platelets and the damaged tissue converts prothrombin into *thrombin*. This in turn helps to change the soluble

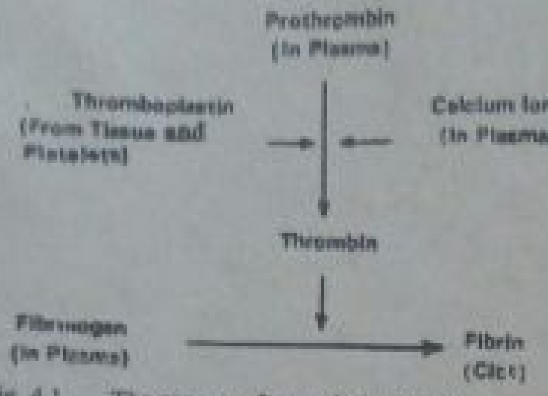


Fig. 4.1 The process of coagulation of blood.

protein of plasma, *fibrinogen*, into insoluble *fibrin*. The fibres of fibrin form the clot in which the corpuscles are entangled. Normally, blood coagulation does not occur in the blood vessels because there is no formation of thrombin due to the absence of thromboplastin. Moreover, a substance called *heparin* interferes with the conversion of prothrombin into thrombin and, therefore, prevents blood clotting. A substance which prevents coagulation is called an anticoagulant, e.g., *heparin*, *hirudin* of salivary glands of leeches, sodium or potassium oxalates and citrates. When one of the important plasma proteins needed for blood clotting, namely, *antihaemophilic globulin* is absent in blood, it clots very slowly. Such persons suffer from the disease called *haemophilia* and bleed excessively even from a small cut.

(f) *Role of blood in temperature regulation*

Blood helps to distribute heat all over the body and thus, to maintain a more or less uniform temperature in different regions of the body. The excess heat is lost from the body by radiation, convection and conduction from the blood as it flows through the skin vessels.

(g) *Role of blood in pH regulation*

Regulation of pH depends upon *blood buffers*. A buffer is a mixture of a weak acid and its salt. Important blood buffers are: bicarbonate buffer of plasma (a mixture of H_2CO_3 and $NaHCO_3$), protein buffers of plasma (sodium salts of plasma proteins and the free plasma proteins), phosphate buffer of plasma and RBC (basic and acidic phosphates of sodium or protein) and haemoglobin buffer of RBC (potassium haemoglobinate and free haemoglobin). The acid member of each buffer neutralises bases entering the blood and the salt member of a buffer neutralises acids (including carbonic acid) entering the blood. The products of such buffer action are also transported by blood to the excretory organs for excretion.

Blood Groups

Blood may be lost during operations or surgery and during injury. When more than 40 per cent of the blood is lost over a short period of time, the body is usually unable to repair the loss unaided. Some artificial means of replacing the lost fluid must be resorted to. The intravenous injection of blood, plasma or serum with the object of restoring the blood volume is called *transfusion*. Blood is usually taken from another healthy individual (the *donor*) and the patient who receives the blood is the *recipient*. However, blood cannot be taken indiscriminately from any person and transfused into any other. Great care must be exercised in the choice of the donor, since the blood of the donor and of the recipient may not mix and may result in its clotting and death of the recipient. The types of blood which, when mixed, behave in this way are termed *incompatible*. As the result of the work of a German biochemist, Karl Landsteiner and others, it has been discovered that the entire human population, irrespective of race or colour of the skin divided into four major groups according to the reaction of their blood when mixed together. The four types of blood, or blood groups are named A, B, AB and O, depending upon the presence or absence in the red blood corpuscles of one or both substances called *antigen A* and *antigen B*. People with the O-type of blood

are *universal donors* as erythrocytes of this type of blood do not have either antigen A or B and so, are not agglutinated by the blood of any other group, so that O-group blood can be safely transfused into any other person (Fig. 4.2; Tables 4.1, 4.2).

TABLE 4.1
Interaction of different blood groups

Corpuscles	Serum			
	O	A	B	AB
O	—	—	—	—
A	+	—	+	—
B	+	+	—	—
AB	+	+	+	—

— no clotting; + clotting

People with the AB type of blood are *universal recipients*. The blood of the donor is 'typed' and matched with the blood of the patient before transfusion. Most of the hospitals have *blood banks* where the different types of blood are classified and stored by freezing. Anticoagulants are added so that blood does not clot. These blood banks are important as the ready supply of the typed blood is available to the doctors in times of emergency operations and for the patients involved in accidents.

TABLE 4.2
Antibody and antigen in different blood groups

Blood group	Antigen in RBC	Antibody in plasma
A	A	anti B
B	B	anti A
AB	AB	none
O	none	anti A and anti B

The Rh factor is a type of blood protein which was found for the first time in the blood of the rhesus monkey. If the factor is present in the blood, the blood is called

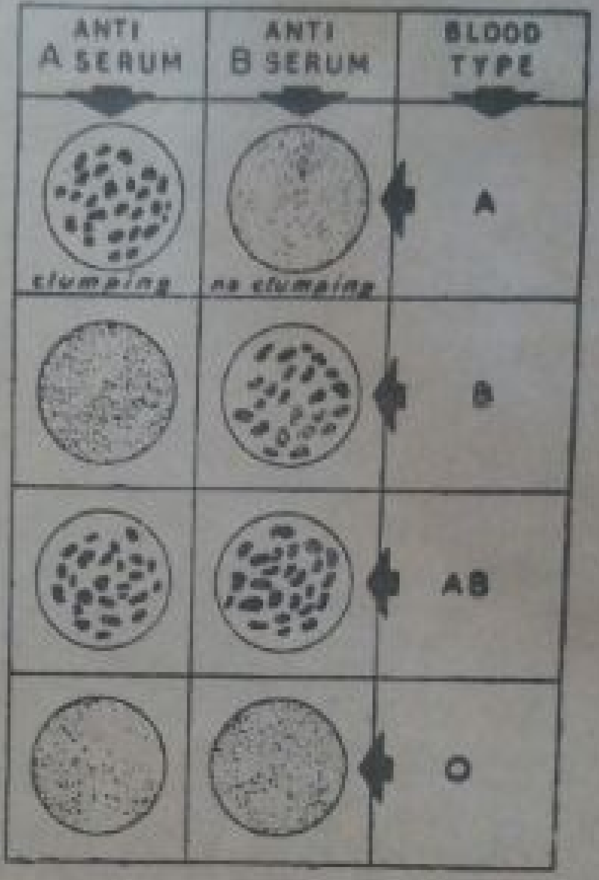


Fig. 4.2 A diagram showing the method of determining blood groups. A drop of given sample of blood is mixed separately into serum containing anti A or anti B substance. The anti serum that brings about clumping of the sample gives the blood type.

Rh positive, if absent, then it is *Rh negative*. If the mother is Rh–ve and the father Rh+ve, the baby is Rh+ve. The Rh+ve factor go from the baby to the circulation of the mother and cause formation of antibodies against Rh+ve factor. The anti Rh+ve protein enters the baby's blood which coagulates, resulting in the death of the baby. This disease is called *erythroblastosis foetalis*.

Blood Circulation

The basic fact of blood circulation was first discovered by an English doctor,

William Harvey. He noted that blood leaves the heart through the arteries and returns to it through the veins. He was also the first to recognise the circulation of blood in a closed system but did not know how the arteries and veins were connected.

ORGANS OF BLOOD CIRCULATION

The chief organs of the circulation of blood are the heart and the blood vessels, namely, the arteries, veins and capillaries.

The Heart: Structure and Function

The heart is a muscular organ which lies above the diaphragm between the two lungs. It is situated almost in the middle of the chest but tilted at its apex to the left. It is enclosed in a double-walled membranous sac, the *pericardium*. The heart is a remarkable organ since it continues working without stopping throughout the life of an individual. The heart of an average person at rest beats 72 times in a minute. It contracts with considerable force and pumps the blood out into the arteries. In mammals, the heart is a four-chambered organ, whereas in frog it has only three chambers.

The right and left halves of the mammalian heart are completely separated by partitions called *septa*. Each half has an upper chamber or the *auricle* and a lower chamber or the *ventricle*. Each auricle opens into the ventricle of its own side through an *auriculo-ventricular aperture*. The two apertures are guarded by *valves* which open only into the ventricle and prevent the back flow of the blood. The *Mitral valve* or *bicuspid valve* having two flaps (Fig. 4.3B) is present at the auriculo-

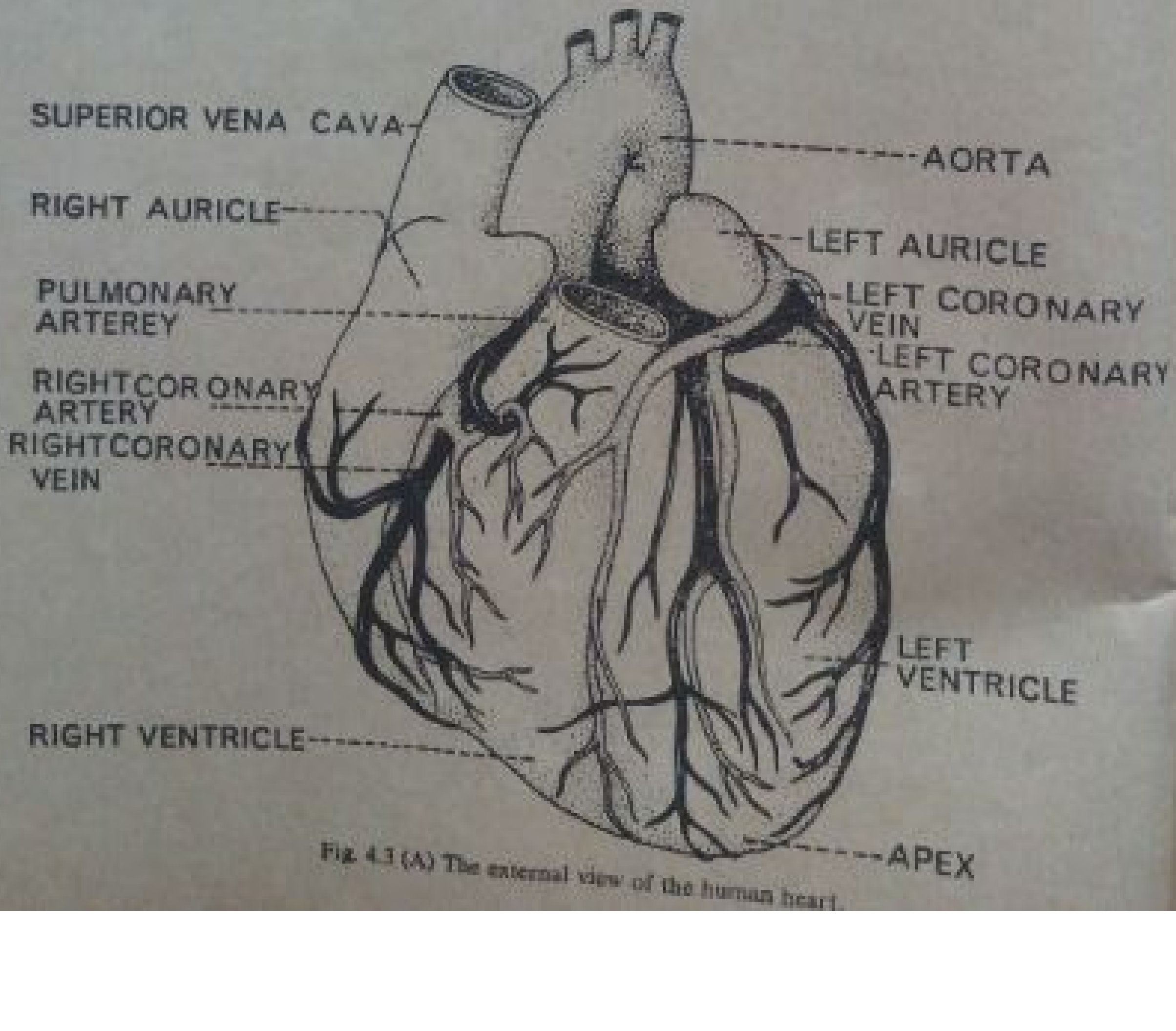


Fig. 4.3 (A) The external view of the human heart.

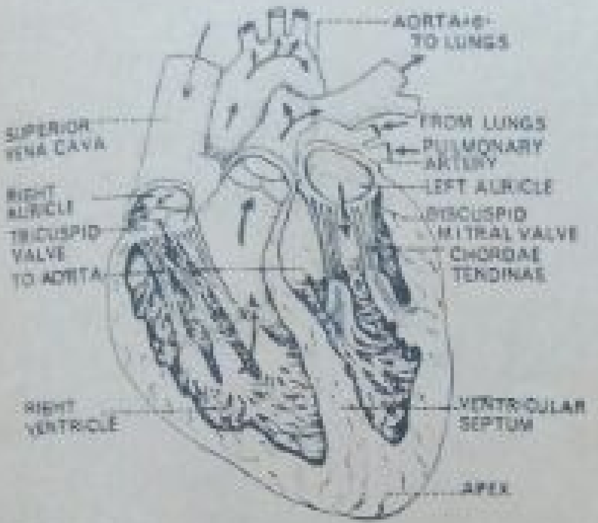


Fig 4.3 (B) The internal view of human heart.

ventricular opening on the left side and the *tricuspid valve* (having three flaps) on the right side of the heart.

The left ventricle has tendinous cords (*chordae tendinae*) and *papillary muscles* which prevent the valves from being pushed into the auricles when the ventricles contract. Similarly, at the starting point of the aorta from the left ventricle there is another set of *semilunar* (half-moon-shaped) valves.

Course of the blood flow in the heart: In mammals, the right auricle receives venous (deoxygenated) blood from the body (except the lungs) through two main vessels—a *superior vena cava* and an *inferior vena cava.* The former brings the blood from the upper regions of the body and the latter from its lower parts. The left auricle receives the oxygenated blood from the lungs through four *pulmonary veins* (Fig. 4.4).

The ventricles are highly muscular, particularly the left ventricle. They receive blood from the respective auricles. When the ventricles contract, the blood is forced into arteries. The presence of valves prevent the blood from flowing into the auricles. The right ventricle pushes the blood into a large pulmonary trunk which soon divides into two arteries leading to

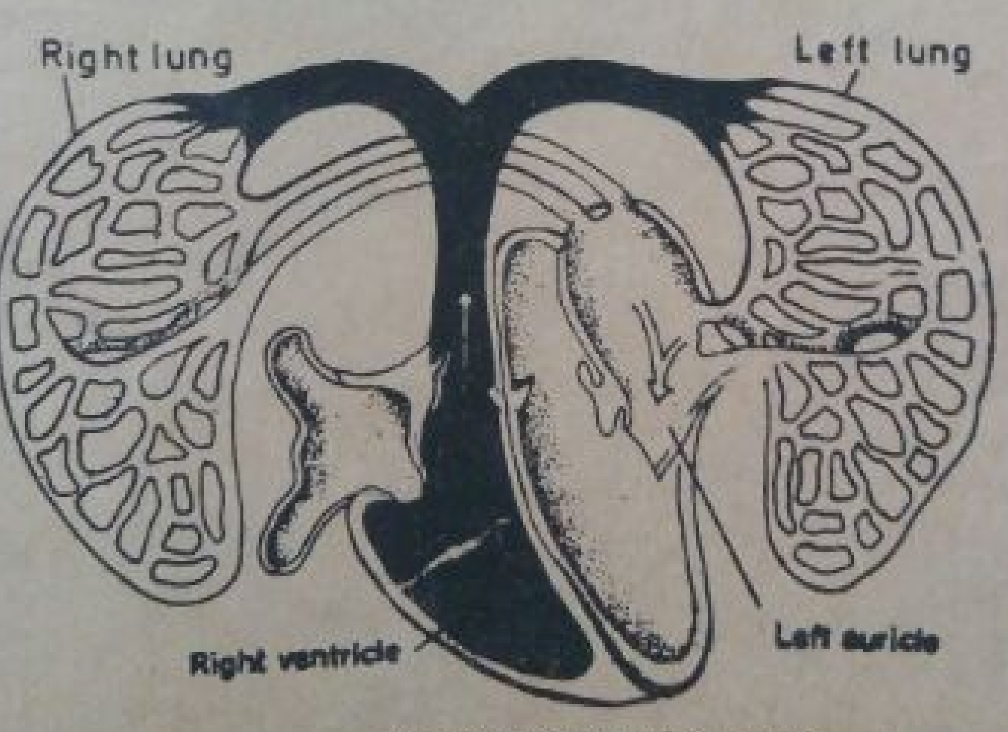


Fig. 4.4 Circulation of blood from the right ventricle to the left auricle.

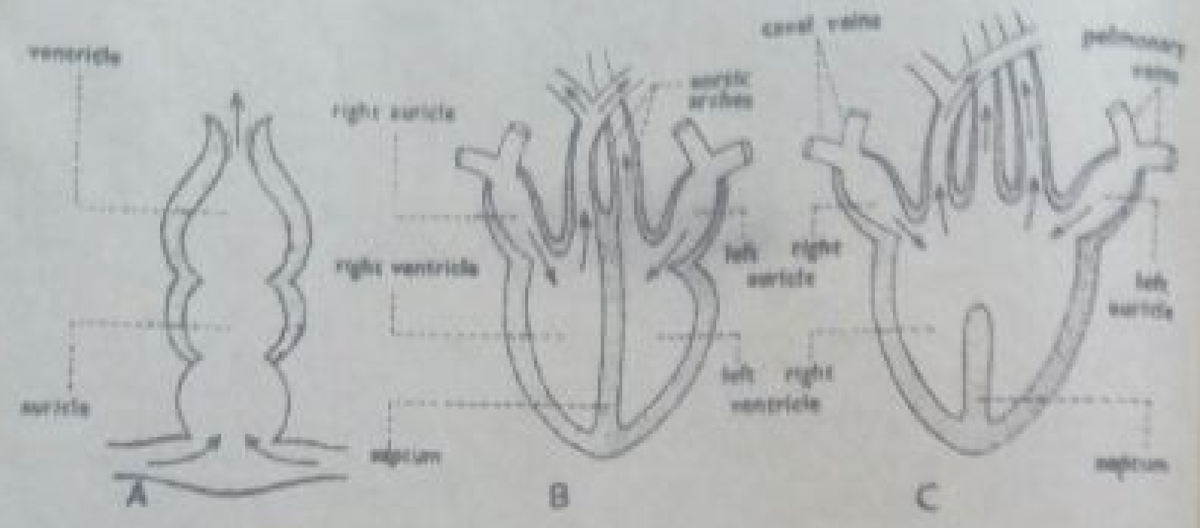


Fig. 4.5 A. single circuit, B. double circuit and C. intermediate type of heart.

the respective lungs (Fig. 4.4). The left ventricle pumps the blood into the thick *aorta* or the main distributing artery. When the ventricles relax and regain the original size, they draw more blood from the auricles. Blood leaving the ventricles flow only in one direction due to valves located at the base of the pulmonary trunk and the aorta which prevent the return of blood into the ventricles. Fig. 4.6 shows the circulation of blood from the left ventricle to the body and back again to the right auricle.

The Arteries and Veins: Structure and Function

All blood vessels leading from the heart are called the *arteries*, whether they contain oxygenated blood as in the aorta or deoxygenated blood (as in the pulmonary artery). The arteries have thicker elastic and muscular walls than the veins (Fig. 4.7 A, B). The arteries branch into small arteries, arterioles and end in capillaries. The capillaries lead into small venules which form small veins and finally large veins. The veins are thin-walled (Fig. 4.7). The *valves* (Fig. 4.8) in the veins prevent the backflow of the blood. Such a circulatory system is called the *closed circulatory system* and is present in all vertebrates and in some invertebrates such as earthworms and octopuses. Because in such a system, blood circulates only within the closed system of blood vessels and never goes out from these vessels normally. But in many invertebrates like prawn, cockroach and some molluscs, blood pumped by the heart comes out from the blood vessels into open tissue-spaces during circulation; these irregular spaces or lacunae carry the blood to open and wider space called sinuses from which the blood ultimately returns to the heart; such a system is known as the open circulatory system. Body cavities filled up with blood in the open circulatory system form the haemocoel.

In mammals (including man) and birds, the heart is completely partitioned into right and left halves; the former receives and pumps deoxygenated blood while the left half does the same for oxygenated blood. This is known as the double-circuit system (Fig. 4.5 B). In lower vertebrates like fishes, on the other hand, the unpartitioned heart receives and pumps only the deoxygenated blood which flows through arteries to the gills for oxygenation. The oxygenated blood is carried through another set of arteries from the gills to the different organs and tissues and is returned from there to the heart in the deoxygenated form through

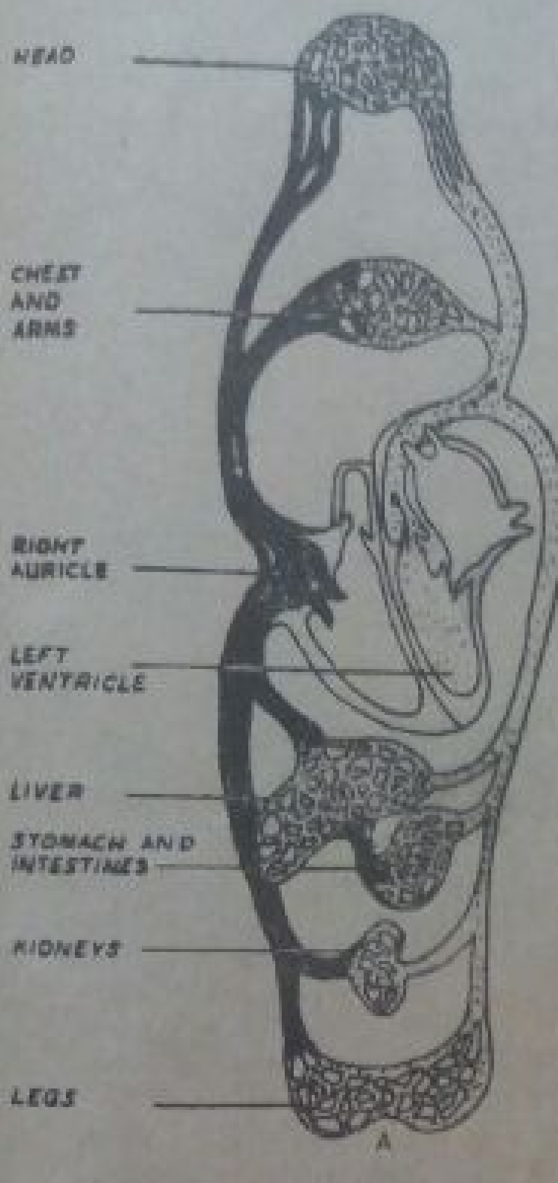


Fig. 4.6 Circulation of blood from the left ventricle to the right auricle.

veins. This type of circulation is a single circuit type (Fig. 4.5A).

In amphibia and reptiles, the heart is incompletely partitioned and receives both oxygenated and deoxygenated bloods which get mixed inside the heart. So, the heart pumps out a mixed blood through the arteries. This type of circulation is intermediate between the single and double circuits (Fig. 4.5C).

The major arteries and veins: The aorta is the main distributing artery of the body. Its first branches are the fine coronary arteries that supply blood to the heart muscles. The aorta then curves upwards and backwards and lies along the backbone (Fig. 4.6, 4.9). From the upper part of the curve of the aorta arise three blood vessels which supply blood to arms, the neck and the head. Along the rest of its path, the aorta gives off branches to the muscles of the chest, to the alimentary canal, liver, kidneys and gonads. Finally, it divides into two branches which enter the legs and pelvis.

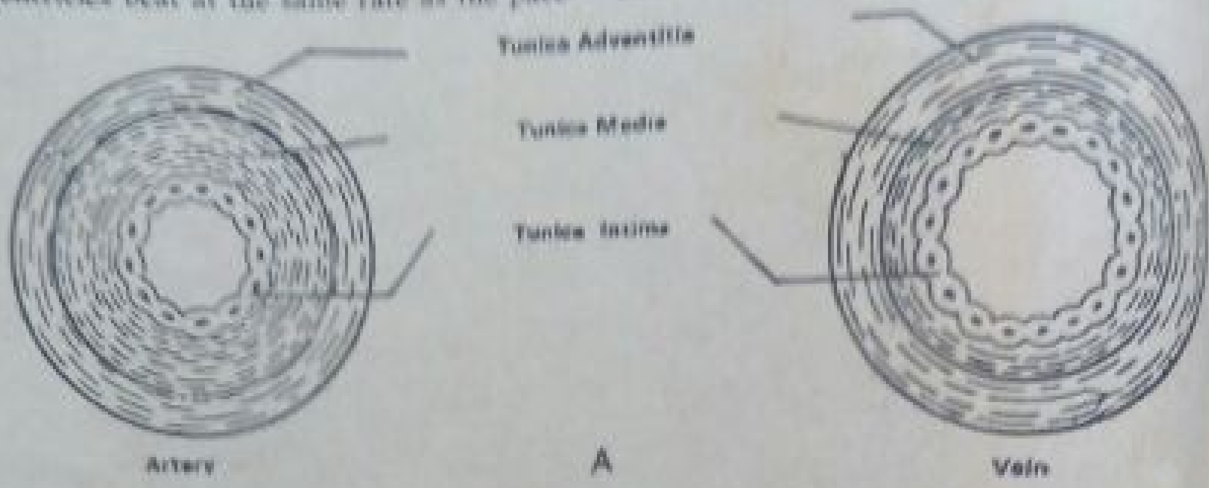
The veins collecting blood from the legs join to form the inferior *vena cava*. The latter in its course towards the heart receives veins from the abdomen gonads, kidneys and liver. The blood returning from the digestive canal is first brought to the liver by a portal vein and after undergoing certain important changes therein (such as deposition of excess sugars in the form of glycogen), it is poured into the inferior vena cava through the hepatic veins. The blood from the upper parts of the body is collected by a number of smaller veins which unite to form the paired *innominate veins*. These in turn join to form the large *superior vena cava* that opens into the right auricle. The coronary vein returns the blood collected from the walls of the heart. As the blood circulates through various organs of the body, it receives or delivers certain substances. Its composition changes constantly as illustrated in Fig. 4.9.

Origin and Conduction of the Heart-beat

(i) *Origin of the Heart-beat:* In the heart, a specialised area of muscle fibres known as the *sinuatrial node* or *sinuauricular node* (Fig. 4.10 A, B) is the region where the heart-beat or contraction originates, the pace of the entire heart is set by the sinuatrial node which is known as the *pacemaker or pacesetter* of the heart. The heart beat is myogenic in

origin as it originates from the sinuatrial node composed of specialised cardiac muscle fibres. In the normal heart, the auricles (atria) and ventricles beat at the same rate as the pace-maker, which is approximately 72 beats per minute.

(ii) *Conduction of the Heart-beat:* The excitation from the sinuatrial node (SA node)



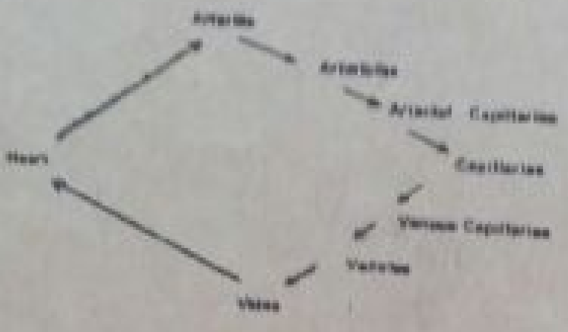


Fig. 4.7 (A) A transverse section of an artery and a vein.
(B) The flow of blood in blood vessels.

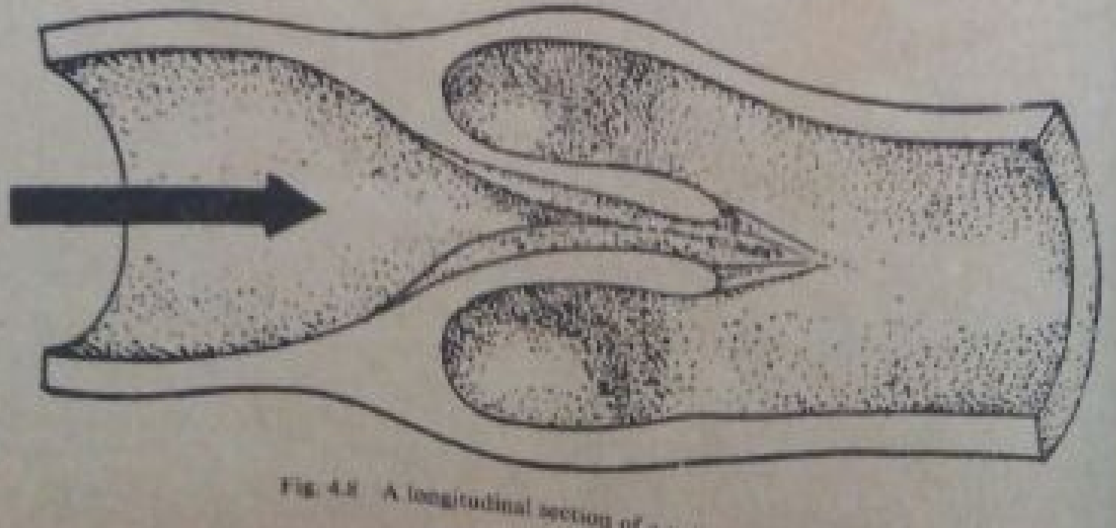


Fig. 4.8 A longitudinal section of a vein sh...

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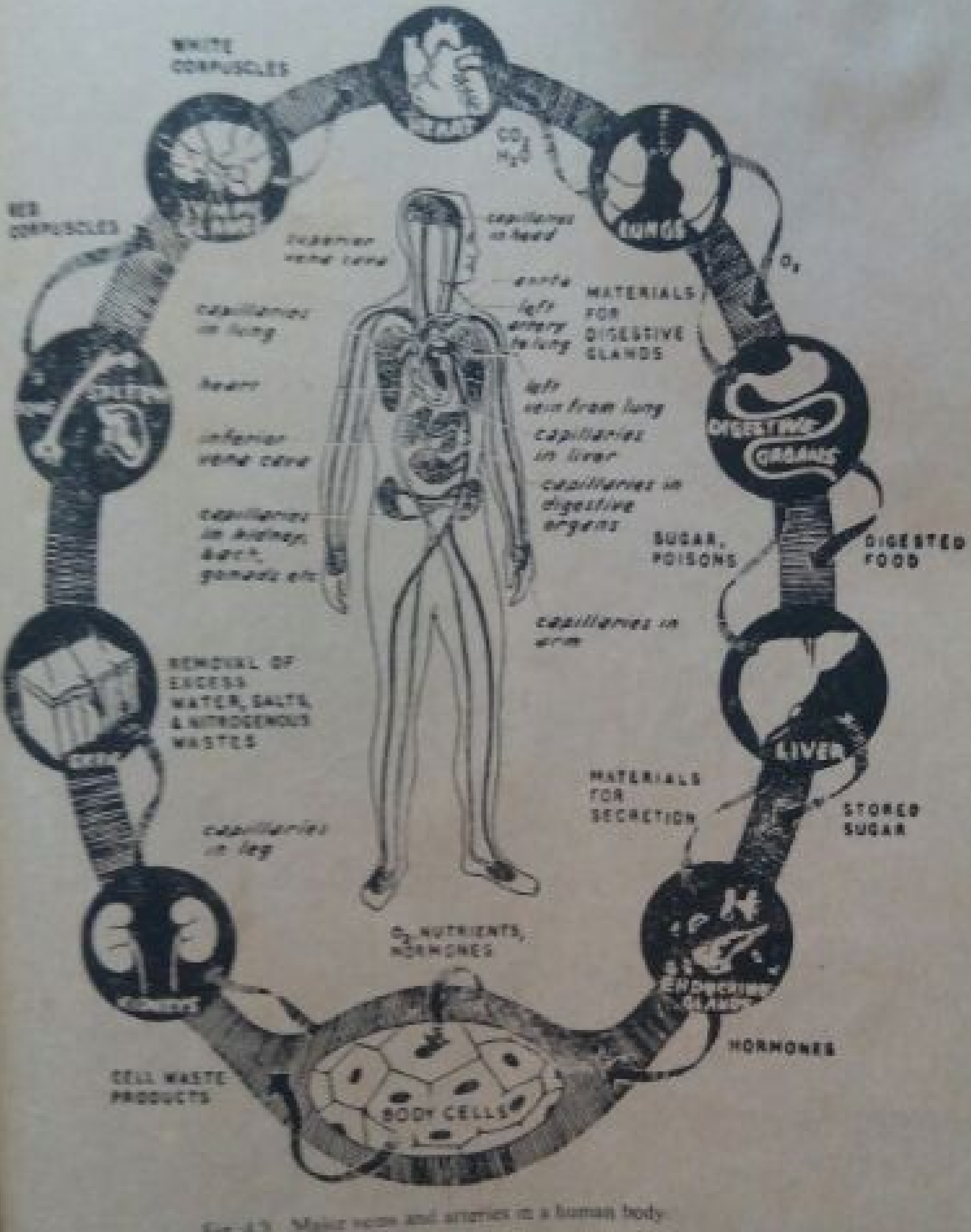
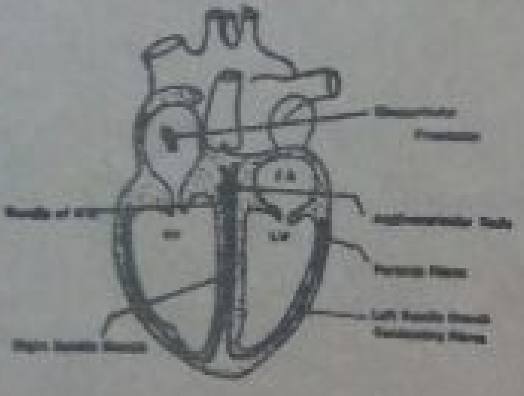


Fig. 4.9 Major veins and arteries in a human body.

radiates through the cardiac muscle fibres of the two auricles, so that the right auricle contracts a fraction of a second before the left atrium. The excitation then reaches the second area of specialised muscle fibres, the *atrioventricular node* (AV node), in the auricular septum (Fig. 4.10). From the AV node, the excitation is sent through special muscle fibres (the AV bundle or *atrioventricular bundle* or the bundle of His in the septum

dividing the two ventricles. This conducting bundle then forms a right and a left bundle branch, each of which enters the ventricles through a fine network of the *Purkinje fibres* (Fig. 4.10).

All the conducting fibres are specialised muscle fibres. Any interference with this conducting system, either by a mechanical obstruction or degeneration due to a disease, impairs the passage of the sinus rhythm and alters the rate of the heart-beat. This is called the *heart-block*. It is possible to implant permanently a small, transistorised pacemaker in the body of such a patient; the wires from the pacemaker are then fixed in that



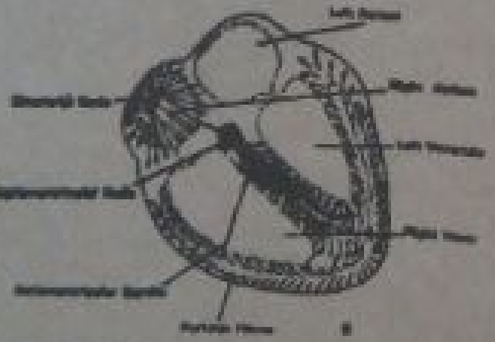


Fig. 4.10 (A) The conducting system of the heart showing the sinuatrial and atrioventricular nodes, the bundle of His and the Purkinje fibres.
(B) The conduction of electrical excitement from the sinuatrial node through the rest of the heart.

part of the heart deprived of the impuls from the SA node. The artificial pacemak is synchronised with the SA node so that entire heart resumes its coordinated cycle. *The heart sounds:* If one places his ear or receiver of the instrument called a *stethosco* upon a man's chest on the left side, the be of the heart can be clearly heard. T sounds can be heard. The first sound *lu* louder and lasts longer than the seco sound *dup*. The first sound is caused by contraction of the ventricular muscles a the vibrations set up by the tight closure the tricuspid and mitral valves. The sem sound is caused by the closure of the aor and pulmonary valves.

Pulse rate and blood pressure: A doct uses a stethoscope to examine the hea beats of a patient. This enables the doc to assess the working of the heart. Ea heart-beat results from the contracti (*systole*) and relaxation (*diastole*) of heart. During the diastole, the two auric become filled with blood poured into th by the veins. In the systole, the blood pumped out of the heart into the arter The two processes take a total of about seconds so that one can feel nearly beats/minute. The beating of the heart also felt in the arteries as regular jerks *pulse*. One can feel the pulse wherever arteries lie near the surface, as on the wr neck and temples.

The flow of blood in the arteries exert pressure on their elastic walls. This press is greater during the systole than during diastole. The two pressures, systolic a diastolic, are usually measured by stethoscope in terms of the pressure exer on a column of mercury. In a normal adu the *blood pressure* (BP), or the systolic diastolic pressures, are 120 mm and 80 mercury (Hg), respectively. It is expressed 120/80 Hg. However, emotions such worry, fear, excitement can elevate the by a rise in the systolic pressure. A persist

elevation can cause *high blood pressure* or *hypertension*. On the contrary, a reduction in the blood pressure causes low BP or *hypotension*. In the old age, the elasticity of the arteries decreases so that the heart has to pump blood with greater force, so the pressure exerted on the walls of the arteries increases, resulting in high BP.

LYMPH AND THE LYMPHATIC SYSTEM

Fluid filters from the blood plasma through the walls of blood capillaries into the tissue spaces to form the *tissue fluid*. Although partly reabsorbed into the capillaries, most of it diffuses into a system of fine channels (*lymph capillaries*) which join repeatedly to form larger *lymphatic vessels*. The fluid inside these lymphatic capillaries and vessels is known as *lymph* and is closely similar to the tissue fluid in composition. Lymph is ultimately returned to the venous blood through two large lymphatic vessels, *thoracic duct* and *right lymphatic duct*, which open into the left and right subclavian veins respectively. The lymph vessels have valves which direct the flow only towards these veins. The additional system of vessels from the lymphatic capillaries to the thoracic and right lymphatic ducts is known as the *lymphatic system* (Fig. 4.11). There are numerous nodular bodies on the lymph vessels like the beads in a string. These are known as *lymphnodes*. In the lymphnodes, the lymph vessel breaks up into fine branches. Phagocytic WBC and macrophages present in the lymphnode remove bacteria and foreign particles from the lymph. Besides 'filtering' the lymph in this way, lymphnodes also form lymphocytes and antibodies (see *Immunity* below) which pass to the blood through the lymph. Lymphnodes are abundant in the neck, arm-pit and groin.

Lymph is similar in composition to blood plasma; but the lymph from organs other than the liver, contains less proteins than plasma because the large molecules of plasma

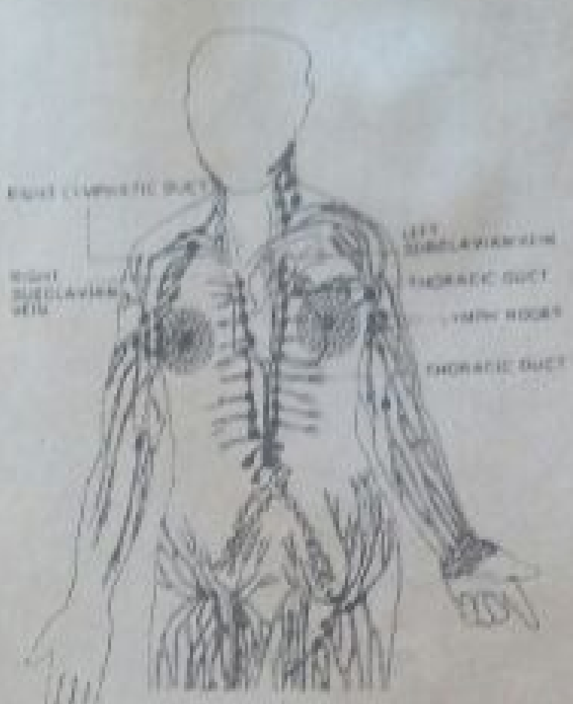


Fig. 4.11 The lymphatic system.

proteins cannot pass out through the capillary walls. Lymph has no blood platelets, but contains lymphocytes.

Tissue fluid and lymph have many *functions* in the body. Tissue fluid supplies nutrients and oxygen to the tissue cells and collects CO_2, waste products, metabolic intermediates and synthesised products (e.g. plasma proteins and hormones) from tissue cells to reach them to the blood through lymph. Lymph carries these materials as also lymphocytes and antibodies (formed in lymphnodes) to the blood. Lymph also transports food fat from intestines to the venous blood.

The spleen is the largest lymphatic organ in the body. It serves three functions. It filters the disintegrated red blood cells from the blood flowing through it; it acts as a reservoir, holding a large amount of blood so that whenever there is haemorrhage (loss of blood), the spleen releases the reserve blood into cirulation. In human embryo it is also the site of formation of both red and white blood cells.

Immunity

Bacteria and microbes cause several diseases in man. The disease-causing germs often release *toxins* which are poisonous. Normally, our body is able to defend itself against most disease-causing microbes. The skin acts as a very effective barrier to the entry of many microbes. The phagocytic nature of white blood cells has been indicated in the earlier part of this chapter. Bacteria are engulfed and devoured by the WBC. Occasionally, the number of bacteria far exceeds the capacity of the WBC to remove them.

Many persons are able to resist diseases to a certain extent due to a chemical reaction in their blood which makes them immune to a disease. The blood of these persons produces substances, called *antibodies*, which fight the invading organisms. Each kind of antibody can act only against one type of microbe. Different antibodies have different characteristics. Some antibodies neutralise the toxins released by microbes. Certain others clump together the microbes which are then easily attacked by the white corpuscles. Some other antibodies dissolve the bacteria.

The substance that causes the formation of antibodies is called the *antigen*. The foreign microbes or the toxins produced by them may act as antigens. Each antigen causes the formation of specific type of antibody which reacts specifically only with that particular antigen to destroy the latter (antigen-antibody reaction). Antibodies are specialised plasma proteins belonging to the group of gamma globulins.

Part of the antibodies sometimes remains in the blood plasma and this serves to protect the individual from future attacks. Such persons are said to be immune to that particular disease. The resistance of our body to a disease is called immunity. If someone readily catches a disease, that person is said to be susceptible to that disease. So, immunity is the power of resisting a disease and not being susceptible to it.

NATURAL AND ACQUIRED IMMUNITY

Some persons are immune to certain d[illegible] eases from birth. These people are said [illegible] have *natural immunity* or inborn immun[illegible] In an epidemic of a particular disease, [illegible] cholera, people with natural immunity [illegible] not suffer from cholera. Moreover, [illegible] people who have once suffered from a dis[illegible] may not be affected again during th[illegible] lifetime. The body retains adequate levels [illegible] antibodies as a protection against fu[illegible] infection. This is called *acquired immunity*.

A person can develop immunity by tre[illegible] ment with appropriate antigens. The imm[illegible] nity caused in an organism by such m[illegible] called artificial or acquired immunity. [illegible] an epidemic of smallpox, the health autho[illegible] ties *vaccinate* the people by which immun[illegible] is produced in a person artificially. Edw[illegible] Jenner, an English doctor, was the first [illegible] discover a safe and effective mean[illegible] producing artificial immunity against sm[illegible] pox. Now, vaccination of children is comp[illegible] sory. The scar which one often finds on th[illegible] arm is due to the vaccination. In vaccinatio[illegible] the host is deliberately infected with a dise[illegible] producing organism. The inoculated su[illegible] stance is called a *vaccine*, which, however, [illegible] very diluted or weakened. The vacc[illegible] against smallpox is produced by infecting [illegible] calf or horse with the smallpox virus. Th[illegible] virus in the calf or horse becomes weake[illegible] This weakened smallpox virus is collec[illegible] as a vaccine and introduced into the hum[illegible] body. Since the virus is weak, it is not a[illegible] to cause a severe form of the disease [illegible] man. But the presence of the virus, thou[illegible] in a weak form, induces the body to prod[illegible] *antibodies* and provides immunity agai[illegible] *smallpox* for at least three years. After th[illegible] re-vaccination is necessary to prolong [illegible] immunity.

The introduction of weakened microbes [illegible] the body induces the production of [illegible] required antibodies after a lapse of some tim[illegible] Such immunity is called *active immunity*. [illegible]

effect of which may last for several years or even a lifetime.

Immunity can also be gained in another way. An experimental animal like a horse is infected with disease-producing microbes. The antibodies are produced in the blood of the horse. The serum of the horse containing the antibody is extracted and introduced into the human body. The human body utilises the ready-made antibodies, thus producing immunity which is known as *passive immunity*. Passive immunity is produced immediately after the serum is introduced into an individual. But the effect lasts only for a short period.

Vaccines are now produced to provide immunity against diseases like whooping cough, diphtheria, measles, tetanus, typhoid, polio, rabies and tuberculosis. Except for measles, the vaccines for the above-mentioned diseases produce active immunity. Both active and passive immunity is produced against tetanus and diphtheria. In our country, the Haffkine Institute at Bombay and the Virus Institute at Poona produce several kinds of vaccines.

ANAPHYLACTIC SHOCK

When the antigen-antibody reaction occurs within the tissues instead of in the blood, a severe allergic reaction is likely to occur. These reactions are characterised by local inflammation as in *urticaria*. The dilatation of arterioles occurs together with the increased release of histamine from mast cells (see Chapter 1, Connective tissue). Dust particles, pollen grains and many other substances function as antigens in an allergic reaction.

Anaphylactic shock is a general allergic reaction involving all the tissues of the body and occurs in a matter of minutes after the injection of an antigen. All the peripheral blood vessels dilate and the capillaries become highly permeable, so that large amounts of fluid leak out from the blood into the tissues. The blood pressure decreases drastically, often resulting in the death of the individual within a short time.

EXERCISES

1. What is the role of pacesetter of the heart?
2. How does the blood clot? What is its need?
3. What are the functions of blood?
4. What is blood transfesion? Who are universal donors and universal recipients?
5. What is the function of valves in the heart?
6. Name the artery that does not carry pure blood and the vein which carries pure blood.
7. What are pulse rate and blood pressure? What are their normal values in a human being?
8. What is the difference between blood and lymph?
9. What is immunity? What is its importance?
10. The vaccine against tuberculosis is called . . . .
11. What do you understand by an allergic reaction?

CHAPTER

Excretory System

EXCRETION is the process by which the metabolic waste products formed as a result of anabolism and catabolism are eliminated from the body. Some of these waste products may become toxic, if they accumulate beyond a certain concentration. An important requisite for the continuation of life, therefore, is the removal of metabolic waste products such as ammonia, urea, uric acid, bile pigments, CO_2, excess salts and water. The organs concerned with this function are the *excretory organs*. In addition to the *kidney* which is the major excretory organ in vertebrates, the skin, lungs, intestine and liver also eliminate metabolic waste products directly or indirectly. Oxidation of sugars and fats in the body gives rise to CO_2 and H_2O because they contain C, H and O only (Fig. 5.1). But during the degradation of proteins, not only CO_2 and H_2O are produced by the oxidation of C and H of amino-acids, but also nitrogenous waste products like ammonia, urea and uric acid are formed from the nitrogen part of amino-acids. Of the different w products, bile pigments are eliminated the bile into the intestine by the liver, CO expelled by lungs in the expired air, and eliminates some salt and water mainly as sweat (see Chapters 1, 2 and 3); but nitrogenous waste products are ma excreted by the kidneys along with more and water.

Excretory Organs in Mammals

The excretory organs are primarily a pa of kidneys, a pair of *ureters*, a *urin bladder* and a *urethra* (Fig. 5.2). The kidn are located in the abdomen, one on each s of the vertebral column just below diaphragm. The last two pairs of ribs prot them. The left kidney is usually placed a li higher than the right one. Each kidney somewhat bean-shaped with a concav along the inner border. Blood vessels, nerv lymph ducts and ureters enter or leave kidney at this point. The gross structure

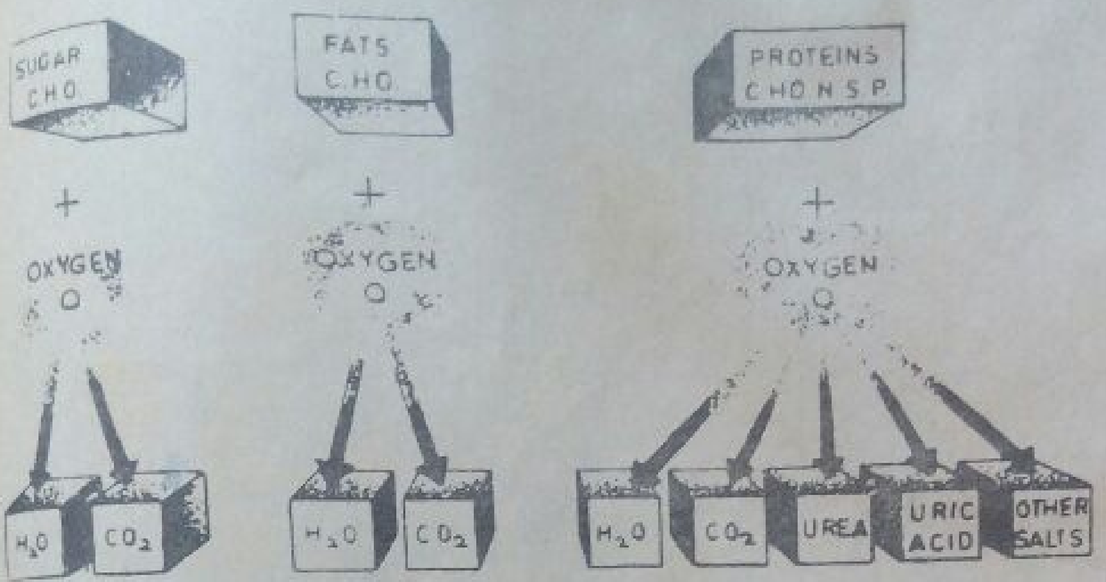


Fig. 5.1 The waste products formed, when sugars, fats and proteins are oxidised.

the kidney (Fig. 5.3) shows two regions, the outer *cortex* and the inner *medulla*. The urine is drained into the *renal pelvis* from where it enters the ureter (Fig. 5.3). The ureters carry the urine to the urinary bladder from where it is eliminated through the urethra.

STRUCTURE AND FUNCTIONS OF THE KIDNEY

Histology of the Kidney

Each kidney is composed of several tiny units, all similar in structure and function. One such unit or *nephron* is shown in Fig. 5.4A. The nephron is made up of a *vascular component*, the *glomerulus* and a *tubular component*, and is surrounded by a network of capillaries (Fig. 5.4B). Throughout its course, the tubule is composed of a single layer of epithelial cells which differ in structure and function in different parts of the tubule. The tubule originates as a blind sac, known as *Bowman's capsule*, which is lined by a single layer of thin epithelial cells (Fig. 5.5). Bowman's capsule is intimately associated with the vascular *glomerulus* which protrudes into Bowman's capsule and is completely covered by the epithelial lining

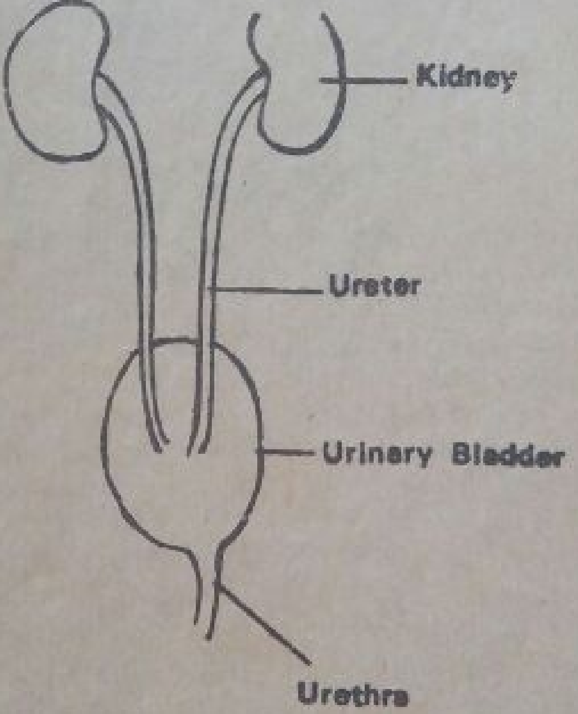


Fig. 5.2 The organs of excretion in a mammal

of the capsule. As is evident from Fig. 5.5, the glomerulus consists of loops of the *afferent* and *efferent arterioles*. The afferent arterioles carry blood to the nephron, whereas the efferent arteriole carries the blood away from the nephron (Fig. 5.5)

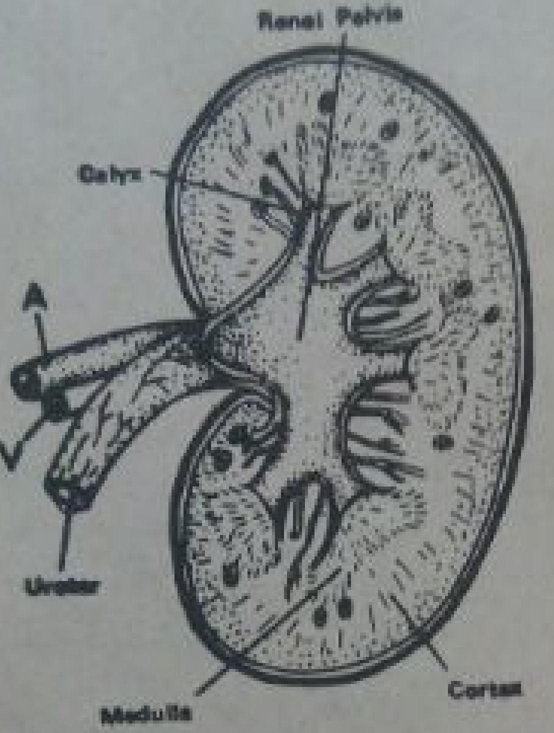


Fig. 5.3 A longitudinal section of the kidney, showing the cortex, medulla, renal pelvis and calyx. A: artery; V: vein.

The functional significance of this anatomical arrangement is that blood in the glomerulus is separated from the cavity within Bowman's capsule only by (1) a thin layer of tissue composed of the single-celled endothelial lining, (2) a layer of material called *basement membrane*, and (3) the single-celled lining of Bowman's capsule. This thin barrier permits the *filtration* of the fluid from the capillaries into Bowman's capsule. The glomerular capillaries combine to form the efferent arteriole which soon divides into *peritubular capillaries* (Fig. 5.4B) distributed in all the remaining portions of the tubule. They rejoin to form the venous channels, by which the blood ultimately leaves the kidney. Bowman's capsule opens into the first portion of the tubule, which is highly coiled and is known as the *proximal convoluted tubule* (Figs. 5.4A, 5.5). The next part of the tubule is a thin loop, called *Henle's loop*, which has a descending and an ascending segment. The tubule again becomes coiled to form into the *distal convoluted tubule*, and finally runs a straight course as the *collecting duct*.

Figs. 5.6 and 5.7 show the histology of the *cortex* and the *medulla* of the kidney.

Functions of the Kidney

(i) The kidney not only removes the waste products from the blood but they also play a very important role in maintaining a constant composition of the blood, irrespective of the nature of the food or fluid intake.

(ii) Urine is acidic in nature. The Kidneys perform an important function in selectively filtering out the acidic substances from the blood into the urine and maintain the correct pH balance.

(iii) The kidneys also regulate the loss of excess water from the body.

The formation of urine involves three processes:

(i) *Glomerular filtration*
(ii) *Reabsorption* of useful substances back into the blood
(iii) *Secretion* of nitrogenous wastes into the lumen of the tubule.

(i) *Glomerular filtration:* The first step in urine formation is the filtration of blood. A large volume of blood flows through the kidneys. The energy for filtration is derived from the hydrostatic pressure of the blood. The glomerular afferent arteriole has a pressure of +75 mm Hg. The osmotic pressure of the plasma proteins (about 30 mm Hg) opposes the pressure exerted by the arteriole (Fig. 5.5). The renal and tubular pressure is about 20 mm Hg, so that the net filtration pressure is 25 mm Hg. A severe fall in the blood pressure would reduce renal filtration.

The glomerular filtration rate in a normal adult is 120 ml/min. The average volume of fluid filtered from the plasma into Bow

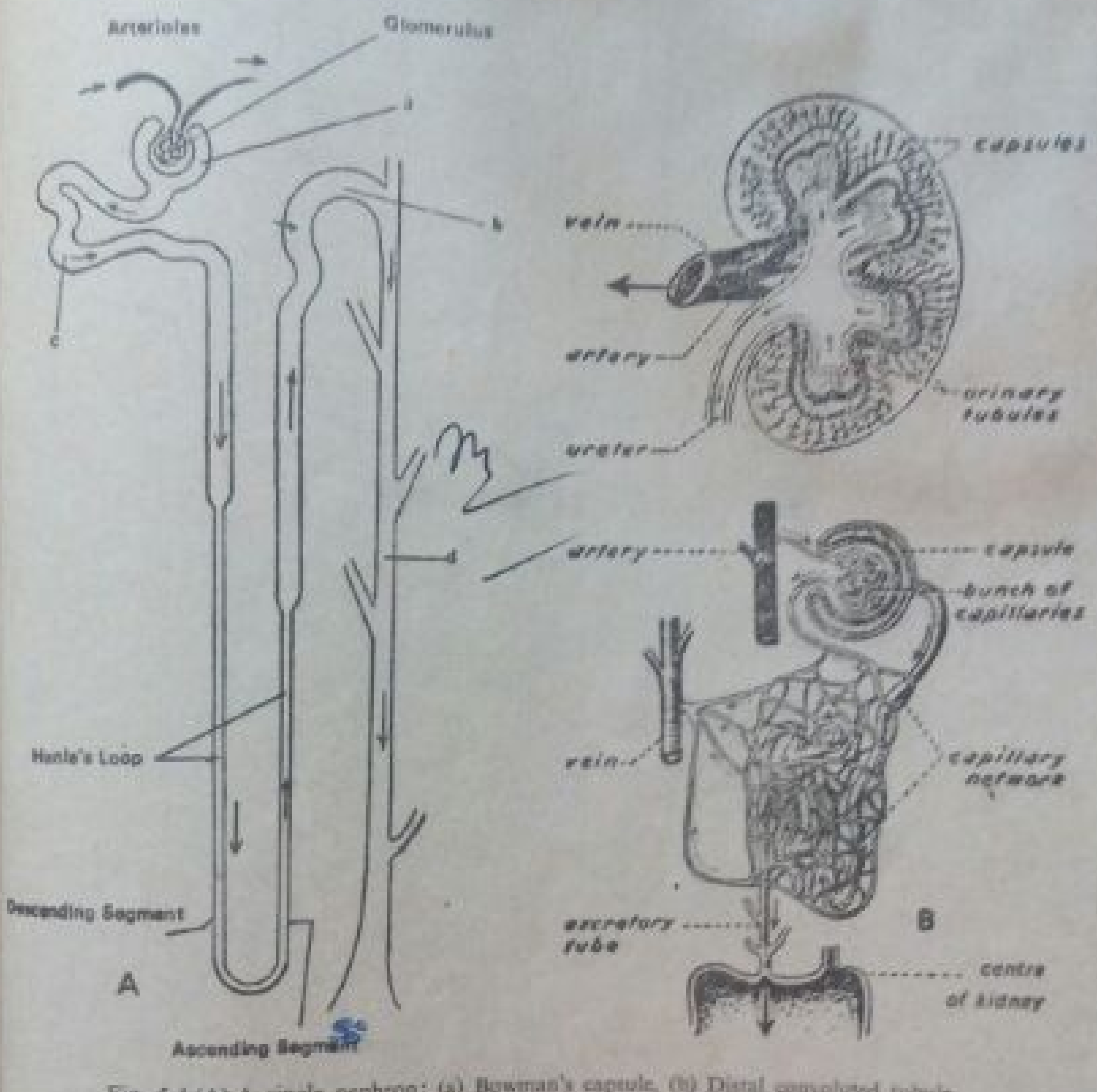


Fig. 5.4 (A) A single nephron: (a) Bowman's capsule, (b) Distal convoluted tubule, (c) Proximal convoluted tubule, (d) Collecting duct.
(B) (upper): Section of kidney showing the flow of urine;
(lower): The blood supply of the nephron.

man's capsule is about 170 litres per day. The ultrafiltrate has the same composition as the blood minus the cells and proteins. The presence of the red blood cells and protein in the urine indicates a defect in the filtration apparatus.

(ii) *Reabsorption:* The cells of the renal tubules are epithelial cells of pyramidal shape with a typical brush border in the proximal convoluted tubule (Fig. 5.7), narrowing down to very flat cells in the loop of Henle. The distal convoluted tubule has columnar cells, whereas the collecting tubules are lined by cuboidal and columnar epithelium in different regions.

The proximal convoluted tubule is responsible for the reabsorption of water, glucose, potassium, phosphate, bicarbonate and sodium. This may be by diffusion but in many cases it involves *active transport*

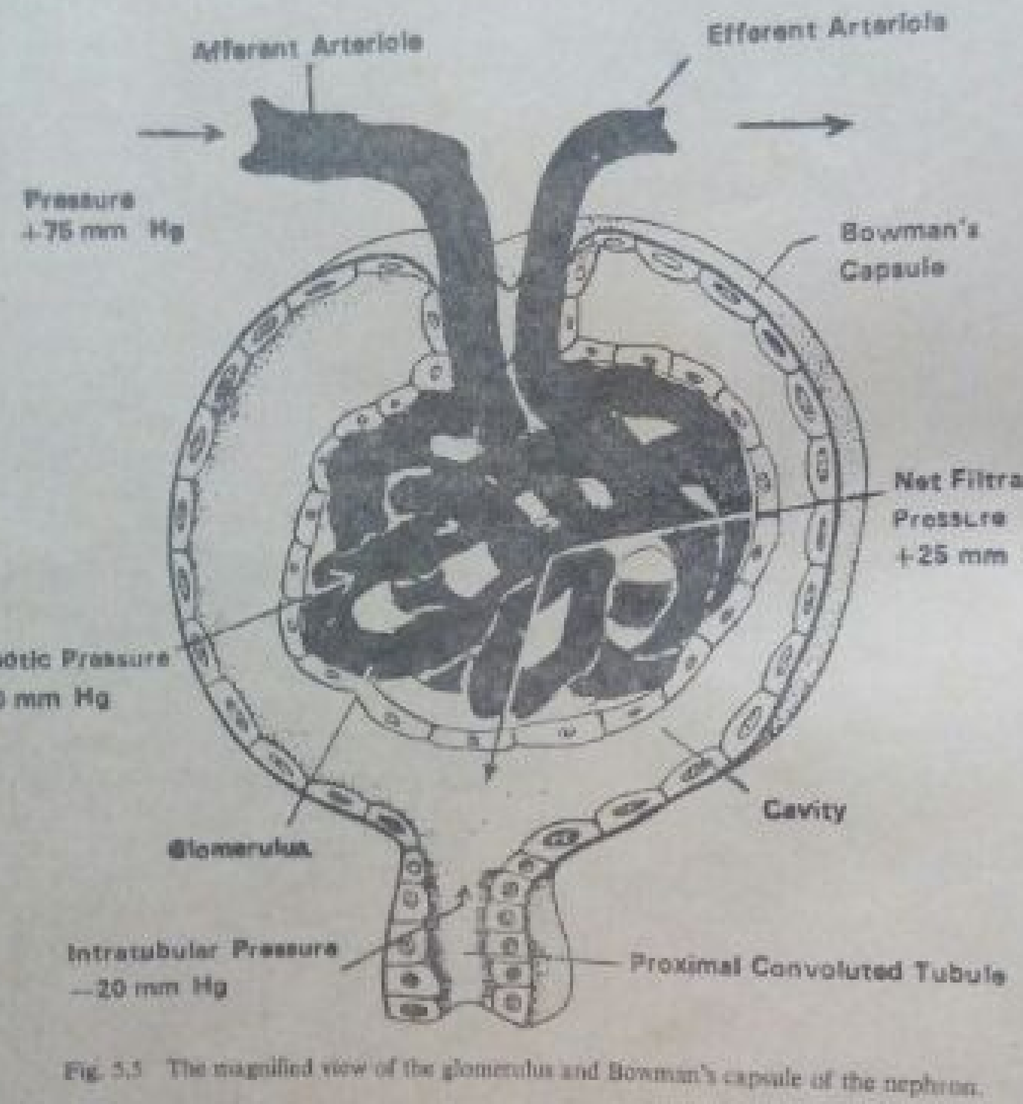


Fig. 5.5 The magnified view of the glomerulus and Bowman's capsule of the nephron.

with the utilisation of energy, e.g., reabsorption of glucose back into the blood. Normal urine, therefore, contains no glucose. But in *Diabetes mellitus*, there is *glycosuria* or loss of glucose in the urine.

The reabsorption of water in the distal convoluted tubule and collecting tubule is partly under the control of antidiuretic hormone (ADH) secreted by the posterior pituitary. When the blood is diluted, as by ingestion of large amount of water, the osmoreceptors in the hypothalamic region of the brain detect the decrease in osmolarity of the blood, and transmit impulses to the pituitary and secretion of ADH is inhibited; the output of the urine is increased due to reduced reabsorption of water in the distal and collecting tubules and a large volume of water is excreted. In contrast, after the deprivation of water, the blood becomes hypertonic and the osmoreceptors stimulate ADH secretion; the urine is concentrated by increased reabsorption of water in the distal and collecting tubules and its volume is less. A number of drugs as well as alcohol suppress ADH secretion, resulting in the increased urinary flow.

The proximal tubule reabsorbs potassium,

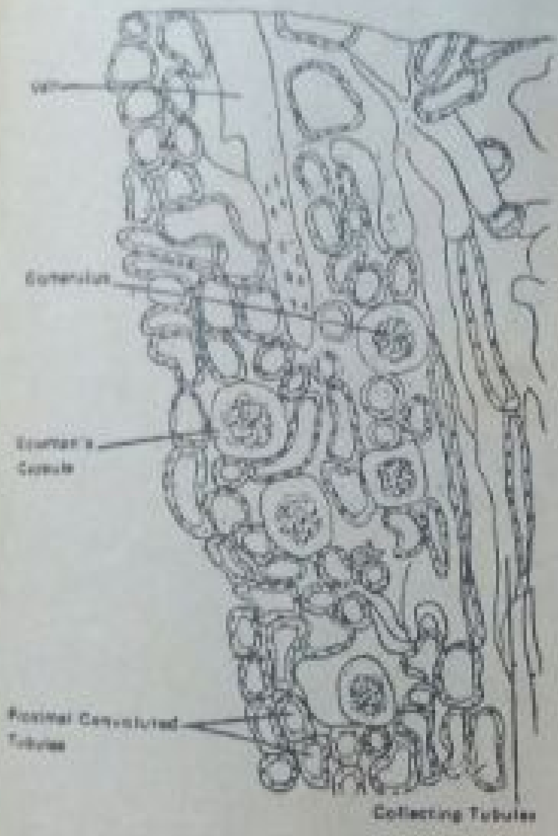


Fig. 5.6 The histology of the kidney cortex.

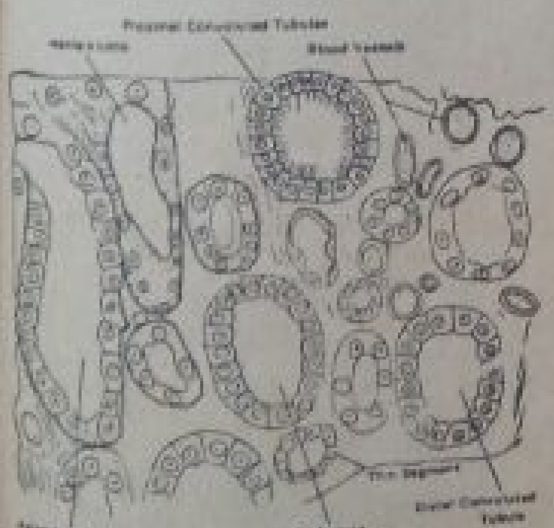


Fig. 5.7 The histology of the kidney medulla.

thus, regulates the amount of acid and base in the blood and consequently its pH.

The distal convoluted tubule is the region where water and sodium are finally reabsorbed against the concentration gradient. The reabsorption of water is regulated by the ADH from the posterior pituitary and by the cortical hormones of the adrenal cortex.

(iii) *Tubular secretion* : Cells of proximal and distal tubules may actively secrete some substances in the urine. The main substances secreted by the renal tubules into their lumen in mammals are K^+, hippuric acid, ammonia creatinine and very little uric acid.

Regulation of Water and Salts

As mentioned above, the excretion of water is regulated by ADH, whereas the control of sodium excretion depends upon its reabsorption. The reabsorption is controlled in part, by a hormone called *renin* produced by the kidneys which, in turn, influence the conversion of *angiotensinogen* into *angiotensin* (produced in the liver). Angiotensin stimulates the adrenal cortex to produce aldosterone which finally influences the level of sodium in the blood. *Osmoregulation* is another means of regulating water in the body.

Animals living in sea-water with high salt concentration face the problem of conserving water. They can resist the changes in salt concentration of the sea-water by making adjustments. This capacity is called *osmoregulation*. The process of *osmoregulation* in fresh-water fishes, amphibians and marine (sea-water) fishes is illustrated in Figs. 5.8 and 5.9. A fish living in fresh water has a higher salt concentration in its blood and tissues than that in the water and, therefore, loses salt when water enters its body. The salt loss is made good by active absorption of salt in the gills and water is eliminated as urine (Fig. 5.8). A fish living in the sea loses water continuously because the salt concentration in sea-water is higher than in the blood and tissues of the fish. The extra salt

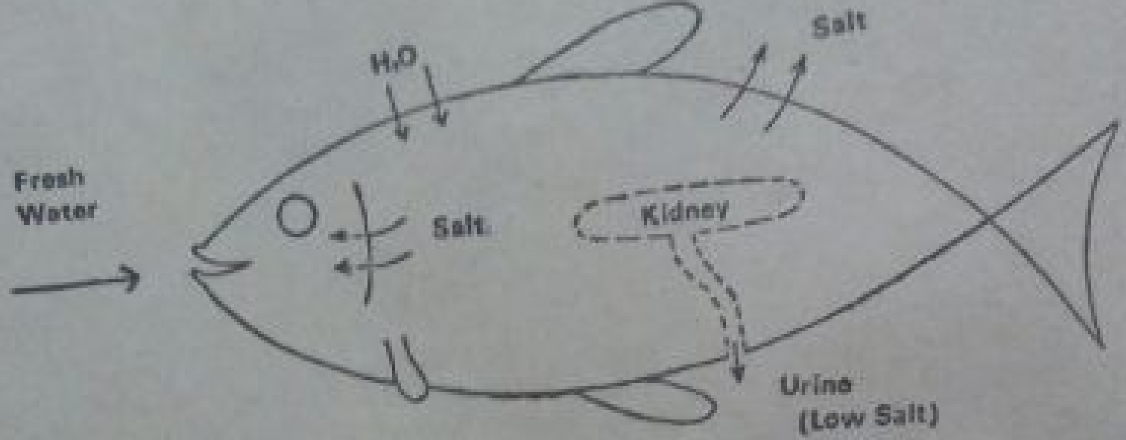


Fig. 5.8 Osmoregulation in a fresh-water fish.

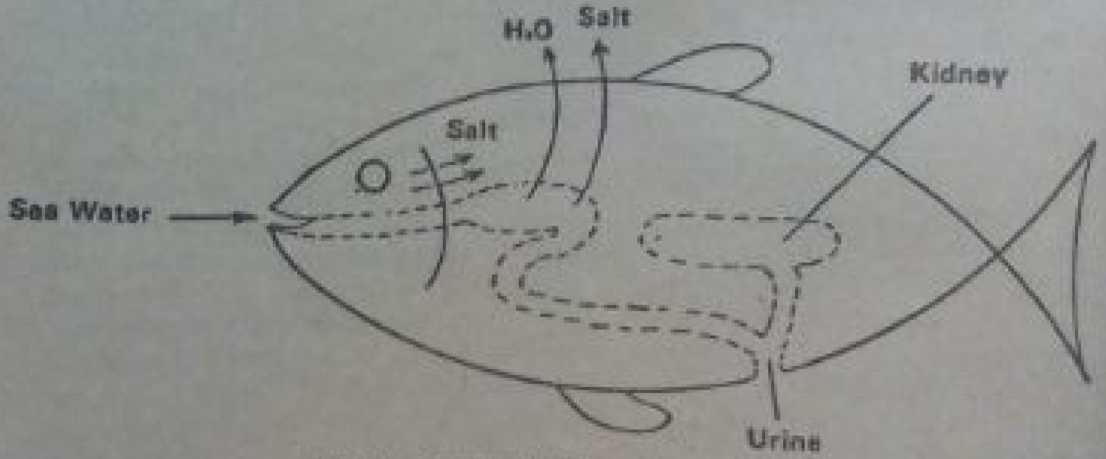


Fig. 5.9 Osmoregulation in a salt-water fish.

which enters its body is excreted by the gills (Fig. 5.9).

Nitrogenous Waste Products

(i) *Excretion of Ammonia (Ammonotelism)*

Ammonia is one of the immediate products of degradation of the amino acids. However, it is extremely toxic and is eliminated in some aquatic organism by diffusion. Among the vertebrates, teleost fishes and aquatic amphibia excrete ammonia in urine as the chief nitrogenous end product of proteins.

(ii) *Excretion of Urea (Ureotelism)*

Urea is formed by the combination of ammonia and carbon dioxide. It is less toxic than ammonia and is the main nitrogenous excretory product in most higher animals like mammals which have a limited supply of water and in which rapid diffusion of ammonia is impossible. Mammals, many amphibia like frogs and toads and elasmobranch fishes among the vertebrates, and the earthworms, snails and prawns among the invertebrates form mainly urea by the degradation of

proteins and excrete it in the urine. Although these animals are structurally very different from one another, the enzymes necessary for the production of urea are the same in all of them. Urea is produced mainly in the liver, from where it is carried to the kidney by the blood stream.

(iii) *Excretion of Uric Acid* (*Uricotelism*)

Urea is also toxic in high concentrations. The human body requires about one litre of water everyday to wash out urea and to keep its concentration at a non-toxic level. Reptiles, birds and insects convert ammonia into uric acid which is the chief nitrogenous end product in them. Being almost insoluble in water, uric acid is the least toxic of the nitrogenous wastes and is excreted in that very form. The animals with such a mechanism are able to avoid the loss of water through the urine for excreting the nitrogenous waste products. Uric acid is whitish and accumulates in the cloaca of reptiles and birds, from where it passes out with the faeces. In reptiles and birds, uric acid is formed by the degradation of proteins mostly in the liver and to some extent in the kidney. It is transported by blood to the renal tubules of the kidney where it is excreted and concentrated. Further concentration of uric acid occurs in the cloaca in which the urine is stored temporarily. The wall of the cloaca absorbs more water from the urine, allowing only a minimum of water to be eliminated.

In man and other primates, some amount of uric acid is formed in the body by the catabolism of nucleic acids and eliminated in the urine.

Artificial Kidney

The artificial Kidney is used to replace a non-functional or damaged Kidney in its excretory functions. It works on the principle of *dialysis*. The blood of the patient is pumped from one of his arteries into a cellophane tube suspended in a salt solution of the same ionic concentration as plasma. As the blood flows through the cellophane tube, mineral ions and nitrogenous waste products like ammonia and urea may diffuse out freely from the blood to the surrounding solvent because the cellophane membrane has pores large enough to allow the free passage of those small molecules; thus, the excess of those minerals and nitrogenous waste products are removed from the blood. But the plasma proteins are retained in the blood itself as the pores of the cellophane are too small to allow the passage of their large molecules. Such a process of separating the large solute molecules from the small ones by means of a semipermeable membrane is called dialysis. Finally, the blood thus purified is returned to a vein of the patient.

EXERCISES

1. What are the chief excretory products in human beings?
2. Where does ultrafiltration, reabsorption and secretion of substances take place in nephron?
3. What is the net filtration pressure? How is it obtained?
4. What is the role of ADH? Where is it produced?
5. What are the normal and abnormal constituents of the urine?
6. What is the role of aldosterone?
7. What do you understand by the term osmoregulation?
8. What is dialysis? Explain.

CHAPTER 6

Nervous System

ALL functions of the body are regulated and integrated to ensure the harmonious functioning of the different organs. Such co-ordination of functions is done primarily by the nervous system which consists of the *brain*, *spinal cord* and *nerve*. For example, the impulses for the contraction of muscles, secretion, etc., are conducted by nerves. Co-ordination involves two categories of activities. One is the functioning of the internal organs, and the second is concerned with receiving and interpreting information from the environment. The eyes receive visual signals which are sent to the brain for interpretation. The ears receive the sound waves. The information received from the sense organs determines our reaction. Thus, the nervous system is concerned with two important functions: (i) it regulates the internal environment of the body through its control of the visceral organs, and (ii) it responds to the external environment through the various sense organs.

The nervous system of all vertebrates, including that of men is divisible into two parts: (i) *the central nervous system*, and (ii) *the peripheral nervous system*. The central nervous system (CNS) includes the brain and the spinal cord. The peripheral nervous system consists of different nerves that arise from the brain (cranial nerves) and the spinal cord (spinal nerves).

Central Nervous System

THE BRAIN

The brain is divisible into the fore, mid and hind brain. In relation to the body size of different animals, the human brain shows a great advance over that of any other animal in the size of the cerebral hemispheres, midbrain, cerebellum, medulla oblongata, etc. (Fig. 6.1).

A deep longitudinal fissure divides the *cerebrum* into two *hemispheres* which are connected together by a horizontal sheet of

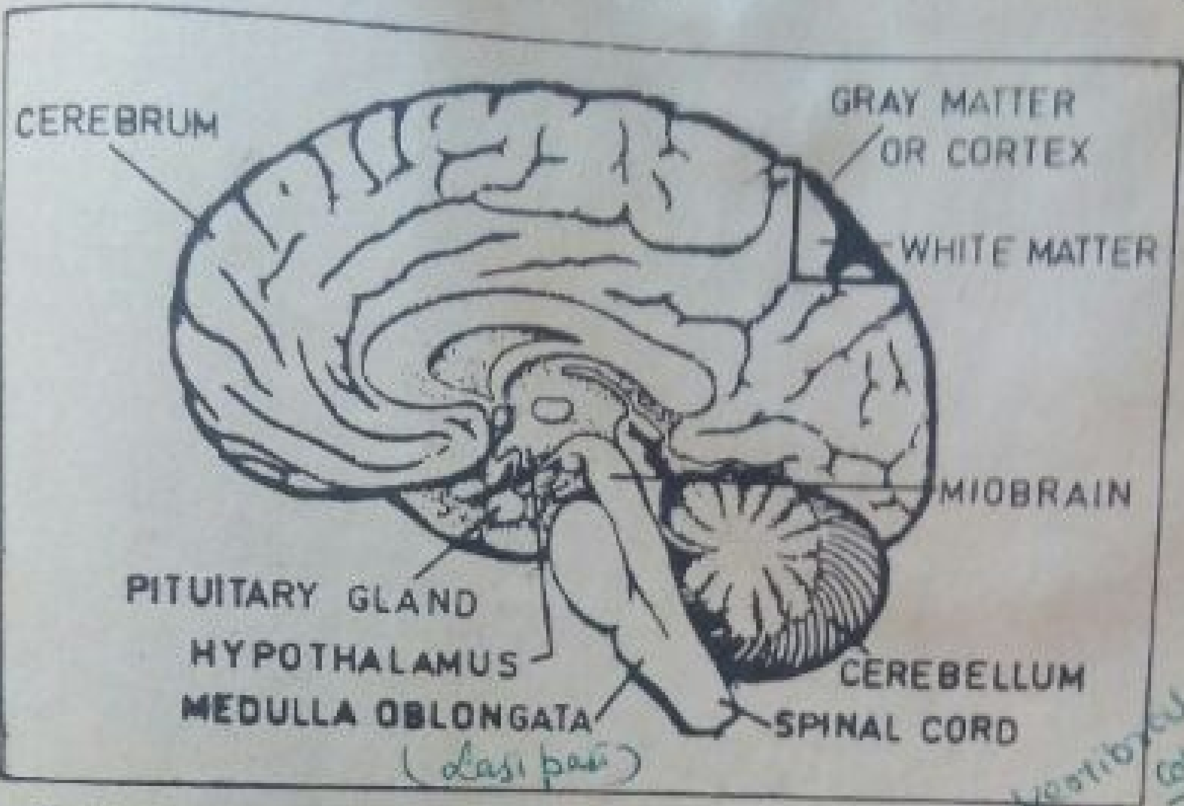


Fig. 6.1 **Human brain**: (A) longitudinal section; Inset location of cortex and white matter.

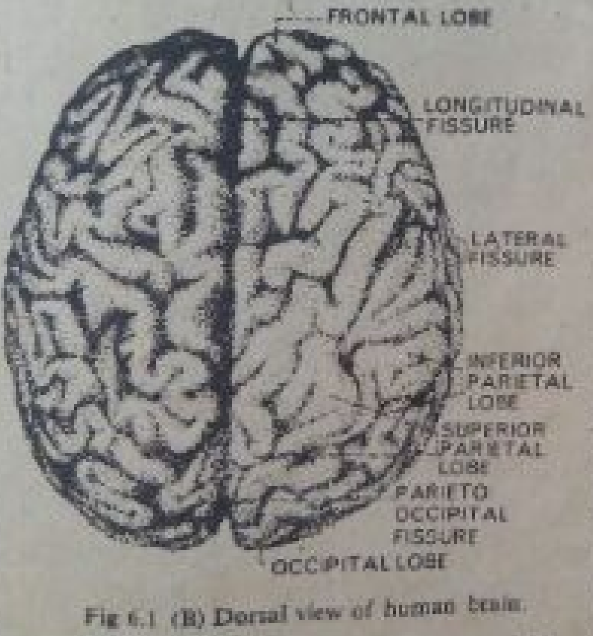


Fig 6.1 (B) Dorsal view of human brain.

nerve fibres, called the *Corpus Callosum*. The surface of the cerebral hemispheres has numerous convolutions. The olfactory lobes are very small and visible only in a ventral view. The cerebral hemisphere control numerous functions of the body, such as thinking, perception of smell, sight, hearing, ability of speech and movements of various parts of the body (Fig. 6.2).

In Chapter 9, functions of the hypothalamus and pituitary hormones regulating the functions of the endocrine glands will be elucidated.

The medulla oblongata continues as the spinal cord which runs in the canal of the backbone or *vertebral column*. The brain and spinal cord are both surrounded and protected by three membranes called the *meninges*, from outside inwards, these meninges are the dura mater, the arachnoid mater and the pia mater. The *cerebrospinal fluid* is a clear slightly alkaline fluid which fills up four irregular cavities or *cerebral ventricles* inside the brain, the sub-arachnoid space between the arachnoid mater and the pia mater, and also the central canal inside the spinal cord. This fluid protects the brain and spinal cord, and helps to maintain a constant pres-

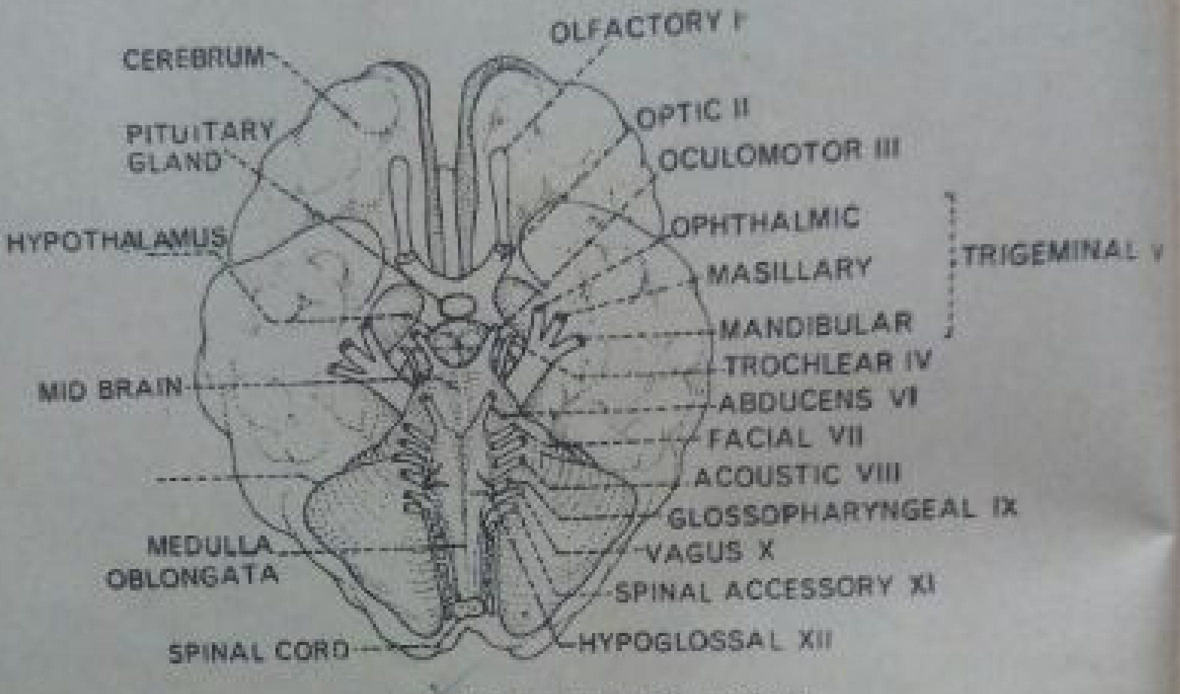


Fig 6.1 (C) Ventral view of human brain.

sure inside the cranium; exchange of the nutrients and waste products may take place between the nerve tissue and this fluid.

The Cranial Nerves

There are 12 pairs of cranial nerves in mammals. The name, nature and distribution of these are given in Table 6.1.

The nerve fibres may be either sensory or motor. *Sensory nerve fibres* conduct nerve impulses from the peripheral tissues or organs (e.g., skin, eye, ear, tongue and nose) to the central nervous system for interpretation or sensation. *Motor nerve fibres* carry nerve impulses from the central nervous system to the muscles and glands for causing their contraction and secretion, respectively.

THE SPINAL CORD

The spinal cord is cylindrical and has the same diameter as of the little finger. The main regions of the spinal cord are shown in Fig. 6.3.

It is divisible into central grey and peripheral white matter. The *grey matter* is largely filled with interneurons, motor neurons, cell bodies and dendrites. The cell bodies of neurons in the grey matter are often clustered together with other neurons having similar functions, into groups called *nuclei*. A narrow central canal traverses the middle region of the grey matter. The peripheral region of the spinal cord is the *white matter* consisting of nerve axons which transmit nerve impulses between different levels of the spinal cord or between the spinal cord and the brain. The fatty myelin coating of these fibres gives the region its whitish appearance and hence its name. The fibres are grouped into bundles, called *pathways* or *tracts*, which are organised according to their function and consist of nerve-cell processes which transmit the same types of information. For example, those nerve fibres which transmit information about light to the brain are all in the same pathway. The spinal white matter contains many tracts, some descending to convey information

TABLE 6.1

Showing the cranial nerves, the organ innervated, the type of fibre and the function of the twelve cranial nerves of man

No.	Cranial nerve	Organ innervated	Type of fibre	Function
1.	Olfactory	Olfactory mucous membrane	Sensory	Smell
2.	Optic	Retina	Sensory	Vision
3.	Oculomotor	Four of the six eye muscles	Motor	Eye movement
4.	Trochlear	Superior oblique eye muscle	Motor	Eye movement
5.	Trigeminal	Skin and mucous membrane of the head	Sensory	Sensation
6.	Abducens	Rectus eye muscle	Motor	Eye movement
7.	Facial	Muscle of the face, neck,	Motor	Movement
		Salivary glands,	Motor	Saliva secretion
		Taste buds	Sensory	Taste
8.	Auditory	Internal ear	Sensory	Equilibrium Hearing
9.	Glossopharyngeal	Pharynx, tongue,	Sensory	Taste, sensation
		Salivary gland	Motor	Saliva secretion
		Pharyngeal muscles	Motor	Swallowing
10.	Vagus	Pharynx, larynx, trachea, oesophagus thoracic and, abdominal viscera	Sensory and motor	Visceral reflexes
11.	Accessory	Thoracic and abdominal viscera	Sensory and motor	Visceral reflexes
		Muscle of the neck and shoulder	Motor	Movement
12.	Hypoglossal	Muscle of the tongue	Motor	Movement

from the brain to the spinal cord, others ascending to transmit impulses in the opposite direction.

Groups of *afferent fibres* enter the spinal cord on the dorsal side of the body (back-side). These groups from the *dorsal roots* are sensory. *Efferent fibres* leave the spinal cord on the front side or ventral side via the *ventral roots*, which are motor. Soon after leaving the cord, the ventral and dorsal roots from the same level combine to form a *spinal nerve*. There are 31 pairs of spinal nerves.

The Reflex Action

When movements occur without necessarily, the intervention of the brain, they are called the *reflex actions* or *spinal reflexes*, e.g., if the knee is hit lightly just below the knee cap, the knee jerks. This is due to a spinal reflex. Similarly, if the finger is accidently pricked by a needle, the hand is suddenly withdrawn. In all these reactions, the sensation of pain is perceived by several pain receptors in the skin which send impulses by the dorsal, sensory roots, to the spinal cord. The sensory neuron synapse with an *interneuron* in the grey matter and finally the impulse is transmitted by the ventral, motor nueron, to the muscle which contracts, resulting in the withdrawal of the finger or hand as the case may be (Fig. 6.4). The entire reaction occurs in the fraction of a second. When the brain is intact, a nerve

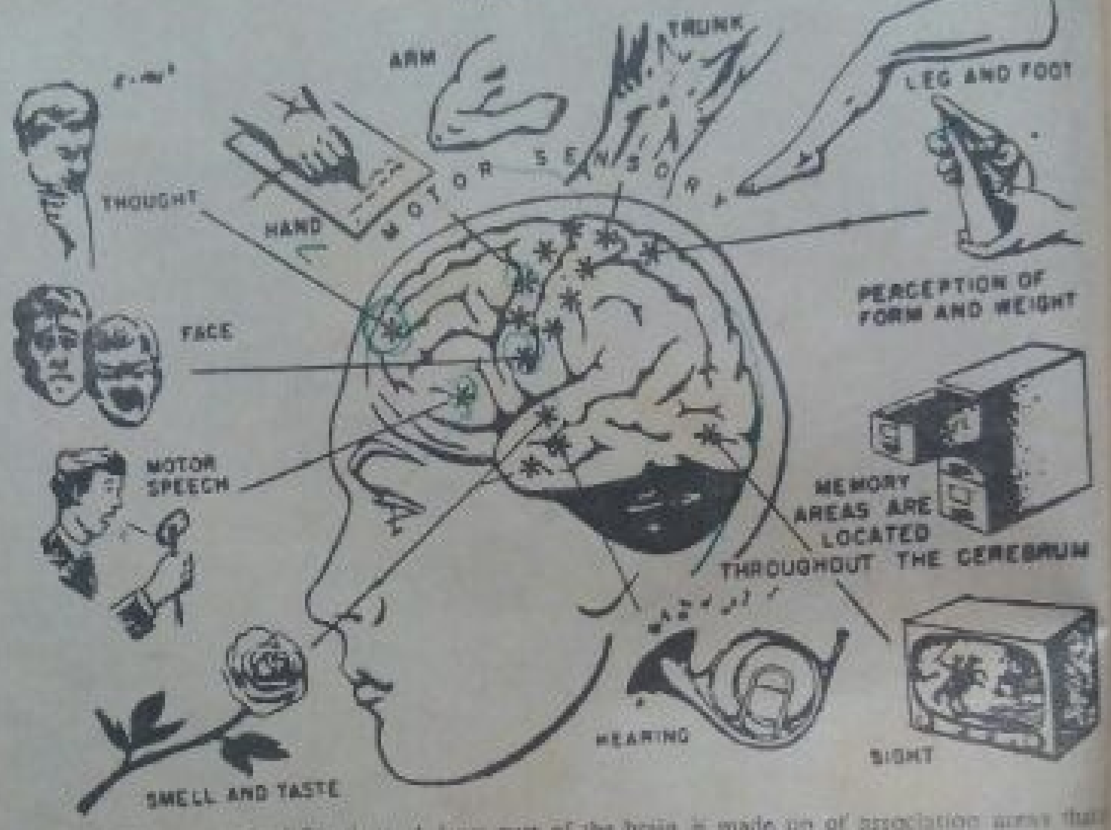


Fig. 6.2 Human cerebral functions. A large part of the brain is made up of association areas that believed to be the centres for memories and for intelligence.

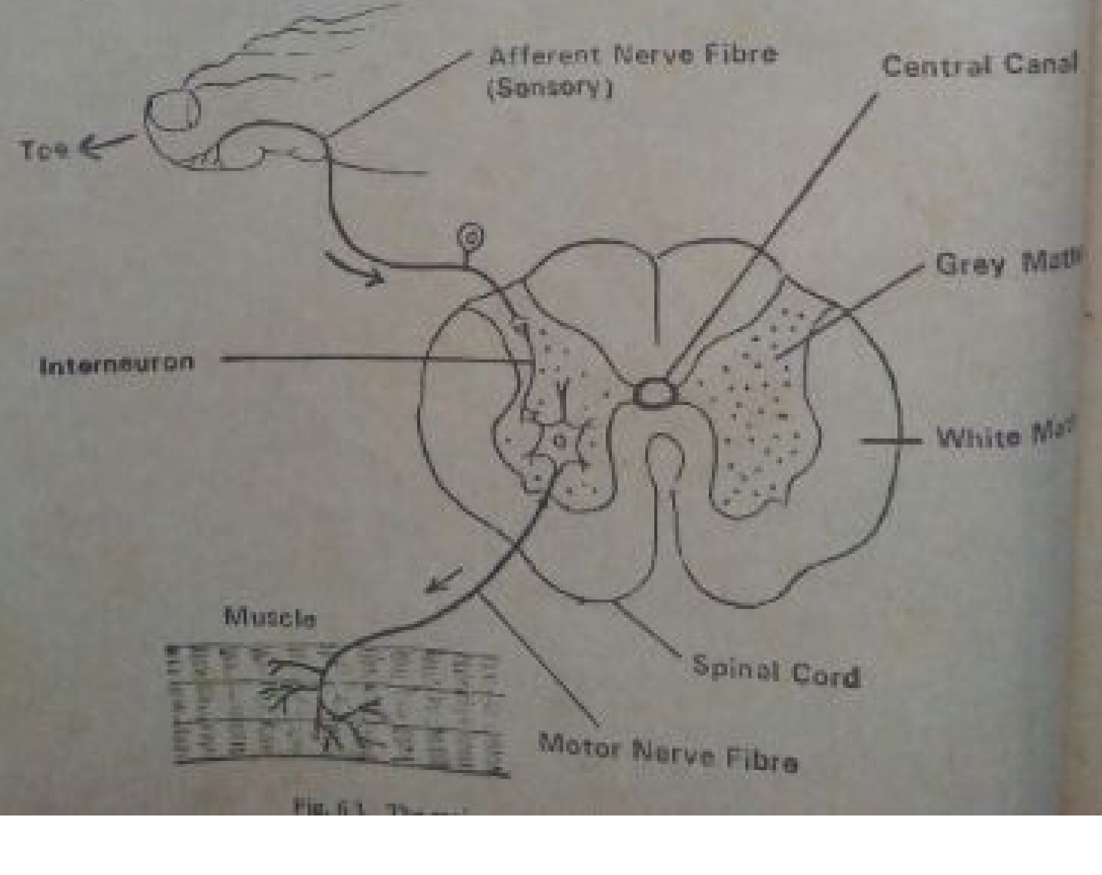


Fig. 6.3 The

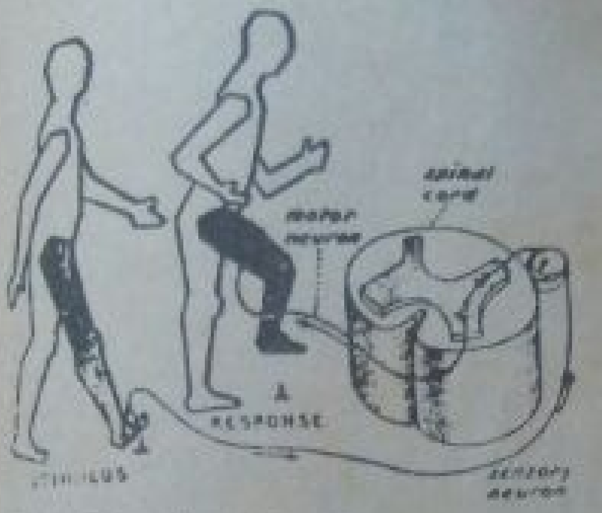


Fig 6.4 The reflex action. If you step on a nail, the prick starts a nerve impulse which is carried to the spinal cord and down it comes back to the leg muscles that make you withdraw your leg instantaneously.

fibre from the spinal cord carries the stimulus to the pain centre of the brain. It is only then, that one feels the pain. Before this, the leg or hand has already been withdrawn as here the nervous response is involuntary and occurs before one is aware of the stimulus. This is called the *reflex action*.

Autonomic Nervous System

The autonomic nervous system consists of two parts, the *sympathetic* and *parasympathetic systems*. The sympathetic system consists of a double chain of *ganglia* (collection of nerve cells), one on each side of the spinal cord. The nerve fibres connect these ganglia with the central nervous system and visceral organs. The ganglia of the parasympathetic system are also paired but these occur nearer to or within the visceral organs. This system has its origin in the brain and in the posterior parts of the spinal cord. The two systems regulate the functioning of all the internal organs of the body which are innervated by both parasympathetic and sympathetic systems (Fig. 6.5). These two systems exert opposite effects on the organs. The sympathetic system usually speeds up or *stimulates* the action of a particular organ, whereas the parasympathetic system slows it down or exerts an *inhibitory* effect on the same organ, e.g., in the working of the heart (Chapter 4), the *vagus* nerve (parasympathetic), which releases acetylcholine, slows down or inhibits the heart, while the accelerator nerves (sympathetic) release noradrenalin (norepinephrine) and increase or accelerate heart-beat. In general, all parasympathetic nerves release acetylcholine at the synapse and most sympathetic nerves release nor-adrenalin or norepinephrine.

It is known that a nerve cell or neuron is specialised for transmitting impulses (see Chapter 1). Each nerve cell has two types of elongated processes (Fig. 1.10). The single *axon* is long and is referred to as the *nerve fibre*. The processes in the second category are numerous, small, branched and are *dendrites*. They receive the impulse from the axon of another neuron and its own axon transmits this impulse to dendrites of the third neuron. These places of contact are called *synapses*, where acetylcholine or norepinephrine is released, and function as *neurotransmitters* for the transmission of the impulse.

Transmission of the Nerve Impulse

Excitability and conductivity are the outstanding properties of the nerve fibre. In the *resting phase* of the axon or nerve fibre, the membrane is 30 times more permeable to potassium ions (K^+) than to sodium ions (Na^+), so that inside the axon there is more potassium and, likewise, more sodium ions are out side the axon membrane than inside it (Fig. 6.6). A normal flux of ions in and out of the membrane also takes place. The resting membrane shows a net +ve charge outside and a −ve charge inside, because besides the Na^+ ions already present outside, a few K ions diffuse out leaving behind the large organic anions inside the membrane.

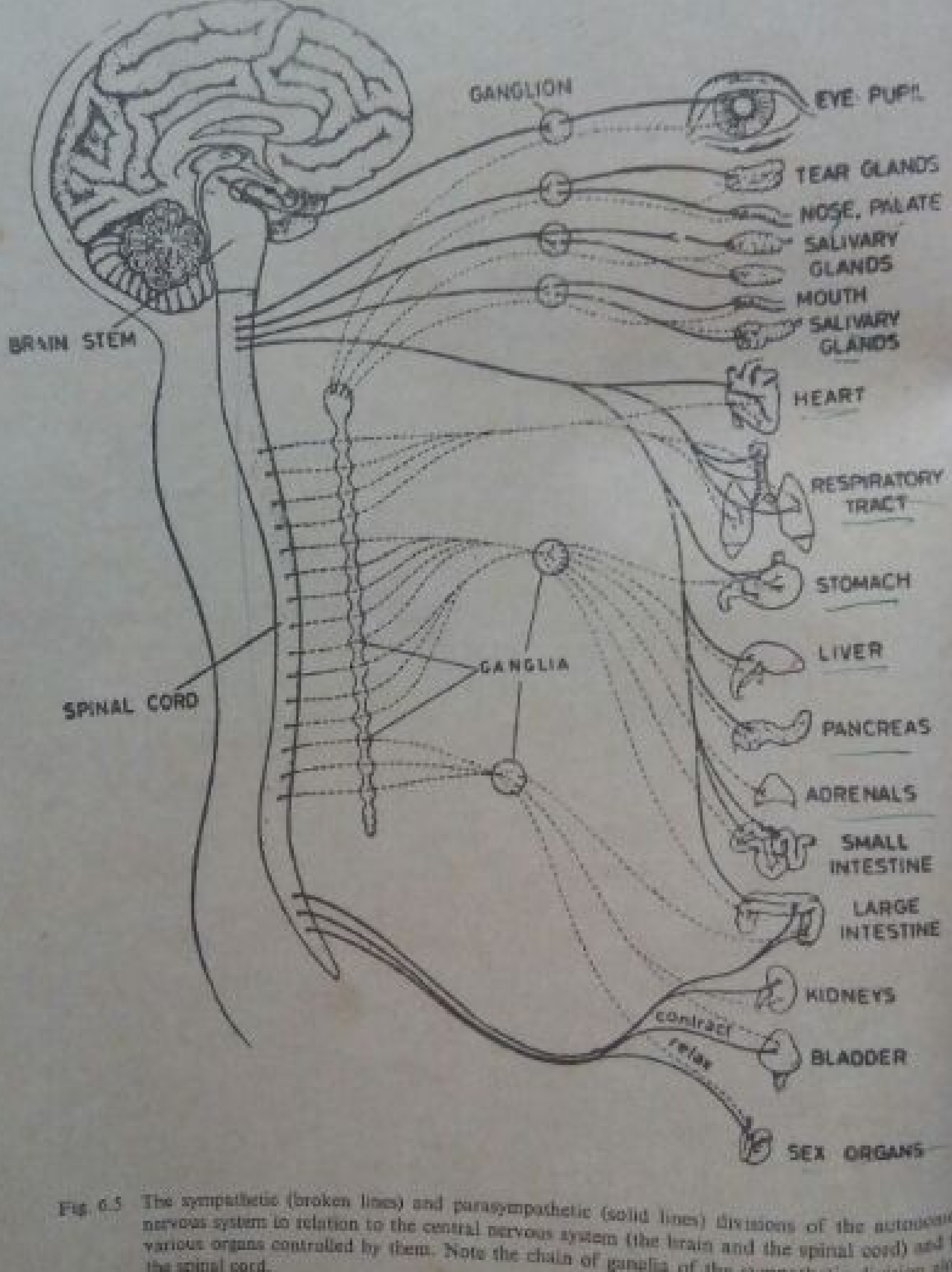


Fig. 6.5 The sympathetic (broken lines) and parasympathetic (solid lines) divisions of the autonomic nervous system in relation to the central nervous system (the brain and the spinal cord) and the various organs controlled by them. Note the chain of ganglia of the sympathetic division along the spinal cord.

This is called the *resting potential* and the membrane is said to be *polarised*. The positive and negative electric charges are balanced on either side of the membrane which remains impermeable to them so long as the nerve is at rest. When the nerve fibre is stimulated *electrically*, *mechanically*, (by pinching), *thermally* (as by the application of a heated glass rod), or *chemically*, a disturbance is set up at the point of stimulation which is called the *local* excitatory state. The membrane is said to be *depolarised*. This spreads as a wave of excitation along the nerve fibre and is called the *nerve impulse*. During this *active phase* of the nerve fibre, the membrane becomes more permeable to Na^+ ions, some of which diffuse inwards across the membrane (Fig. 6.6). Due to the diffusion of ions in this phase, more sodium ions enter the axon than potassium ions leaving it so that the +ve and −ve charges on the outside and inside of the axon membrane are reversed, i.e., the membrane is negatively charged (−ve) on the outside and positively charged (+ve) on the inside. This change in the membrane potential is called the *action potential* (Fig. 6.6). These eletrochemical changes are transmitted down the axon to the synapse and then on to the dendrites of the next neuron.

In the *recovery phase*, the axon is again positively charged on the outside and negatively charged on the inside due to an active transport of sodium ions outside the axon. This process requires energy. An influx of potassium also takes place (Fig. 6.6).

The nerve impulses can travel along an axon at different speeds or *velocities*, e.g., in a mammalian nerve it is 100—125 metres per second.

The Sense Organs

The five senses of the body are those of vision, hearing, smell, taste and touch. These are carried out through the eyes, ears, nose, tongue and skin, respectively. The skin also feels pressure, pain, cold and warmth.

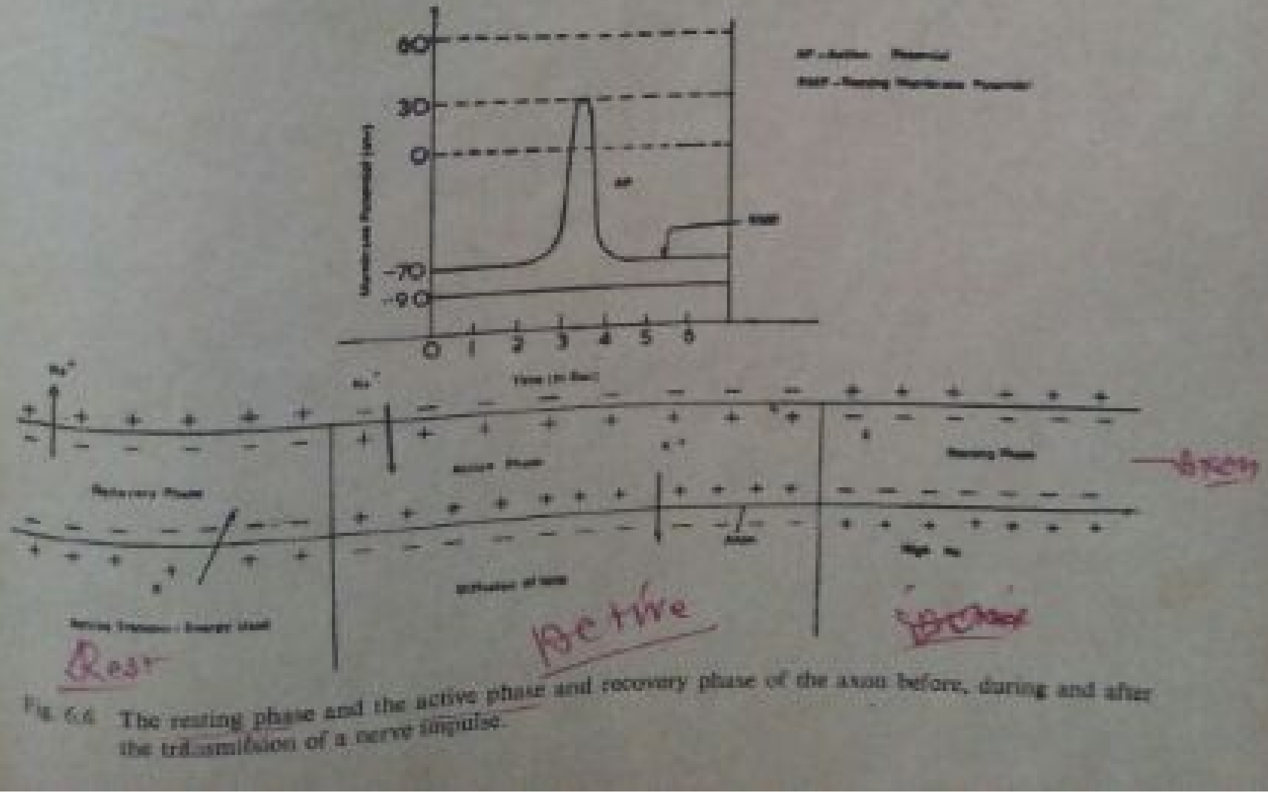


Fig. 6.6 The resting phase and the active phase and recovery phase of the axon before, during and after the transmission of a nerve impulse.

THE EYE

The eyes are lodged in the deep cavities of the skull called *orbits*. The eyelids can rapidly close to prevent dust or other foreign particles from entering eyes. The eyelashes have a similar function. The eyes are flooded with a watery secretion or tears on irritation due to the foreign particle or due to gas or smoke or under certain emotional conditions. The tears are secreted by the tear glands located near the outer border of each eye and drains through minute ducts on the inner surface of the upper eyelid (Fig. 6.7). The movement of the upper eyelid spreads the secretion over the eye.

The wall of each eye is made up of three concentric layers, namely, the outermost is *sclerotic*, the middle one is *choroid* and the innermost is *retina*. The anteriormost part of the sclerotic layer is transparent, bulging circular and is called *cornea*. The cornea can be stored and grafted on to another person. The cornea and rest of the exposed sclerotic layer are covered by another very thin transparent membrane, the *conjunctiva*, which is the continuation of the inner surface of the eyelids. The pigmented iris, formed by the choroid layer has a central aperture called the *pupil* visible from outside as a dark window. The iris consists of circular and radiating muscle fibres which regulate the size of the pupil and consequently control the amount of light passing to the retina. Just behind the pupil lies a biconvex *lens* which is held in position by ligaments and muscles. The thickness of the lens is controlled by smooth muscles called *ciliary muscles*. A transparent watery fluid, the *aqueous humour*, fills the space between the lens and the cornea (Fig. 6.8A). The large chamber behind the lens is filled with a clear, gelatinous substance, the *vitreous humour*.

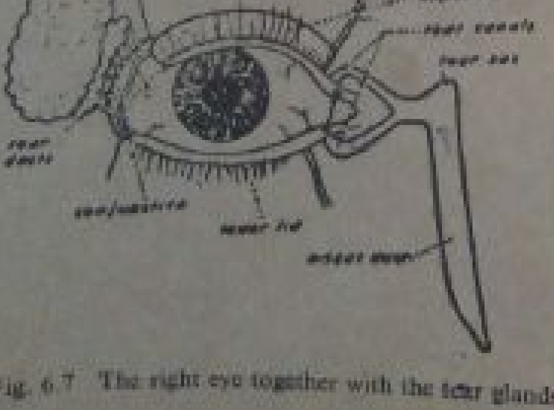


Fig. 6.7 The right eye together with the tear glands.

The sensory layer or *retina* consists of two types of cells, the *rods* and *cones* (Fig. 6.8B). The rods are sensitive to dim light and contain a brown pigment, called *rhodopsin*, which is formed from vitamin A. The rods enable us to see shades of grey and white and in dim light as well as in the dark. If the food is deficient in vitamin A, one is unable to see anything in dim light. This defect is called *night blindness* (see Chapter 2) and results from insufficient rhodopsin in the rods. The cone cells are sensitive to bright light and enable us to see the three primary colours, i.e., red, green and blue. There are three types of cone cells, each having a different pigment. The absence of any one of these results in a failure to see the corresponding colour. Those who have no cones in their retina cannot see any colour and they suffer from *colour blindness*. The cone cells are most numerous at the back of the eye opposite the pupil. This is a somewhat depressed part and is known as the *yellow spot* or *fovea*. Vision is the sharpest here. The sensory fibres from the retina bundle together and emerge from the back of the eyeball as the *optic nerve*. At the exit of the optic nerve, there are no rods or cones. A part of the image falling at this place is not perceived, and so this place is called the *blind spot*.

The rays of light falling on the retinal cells generate impulses which are carried by the optic nerve to the brain. The impulses are analysed in the visual area of the brain. It is only then, that one knows that

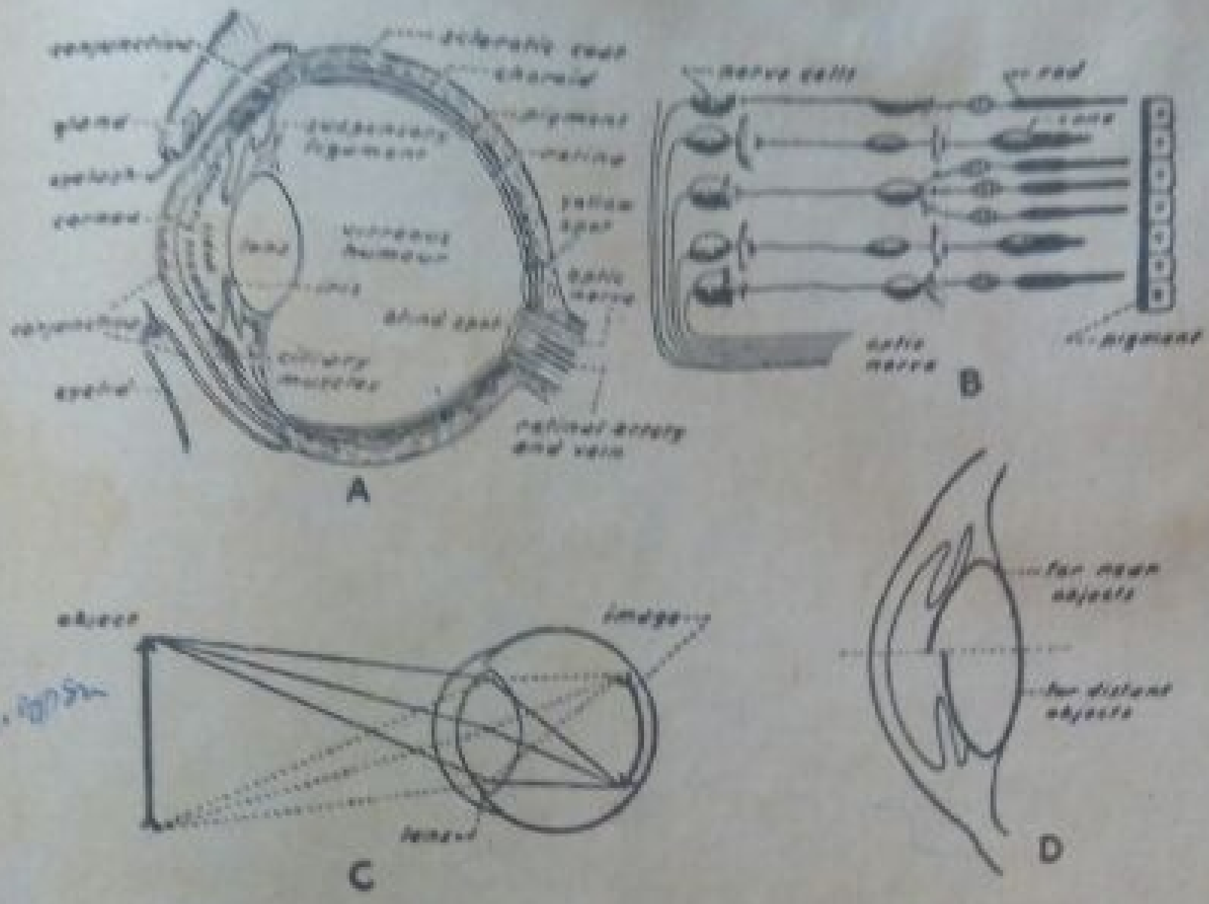


Fig. 6.8 The human eye.
(A) Median vertical section; (B) A small part of the retina enlarged to show the nerves, rods, cones and pigment cells; (C) The lens serves to forman image (reduced and inverted) on the retina; (D) Changes in the shape of the lens to focus the near and distant objects (accommodation).

an object has been seen. If the optic nerve is cut, one cannot see anything as the impulses do not reach the brain.

When one looks at an object, its image is formed on the retina. This image is inverted as in a camera. However, after the brain has analysed it, one gets the upright impression of the object. The image is focussed by the lens on the yellow spot. In a camera, the image is focussed by moving the lens forward or backward. In the eye, the lens does not change its position for focussing; it changes its curvature. For focussing distant objects, it becomes more flattened; and for nearby objects, more convex. This is possible by a process called *accommodation* (Fig. 6.8 C,D). The pupil of the eye becomes wider in dim light and, thus, lets in more light. In bright light, however, it becomes smaller and allows less light to enter.

Common Defects of the Eye

(i) *Myopia* or *Near-sightedness* occurs when the image of a distant object is focussed in front of the retina (Fig. 6.9). This may be due to lengthening of the eyeball from the front to the back or may be due to the increased convexity of the lens. It can be corrected by using appropriate concave lenses.

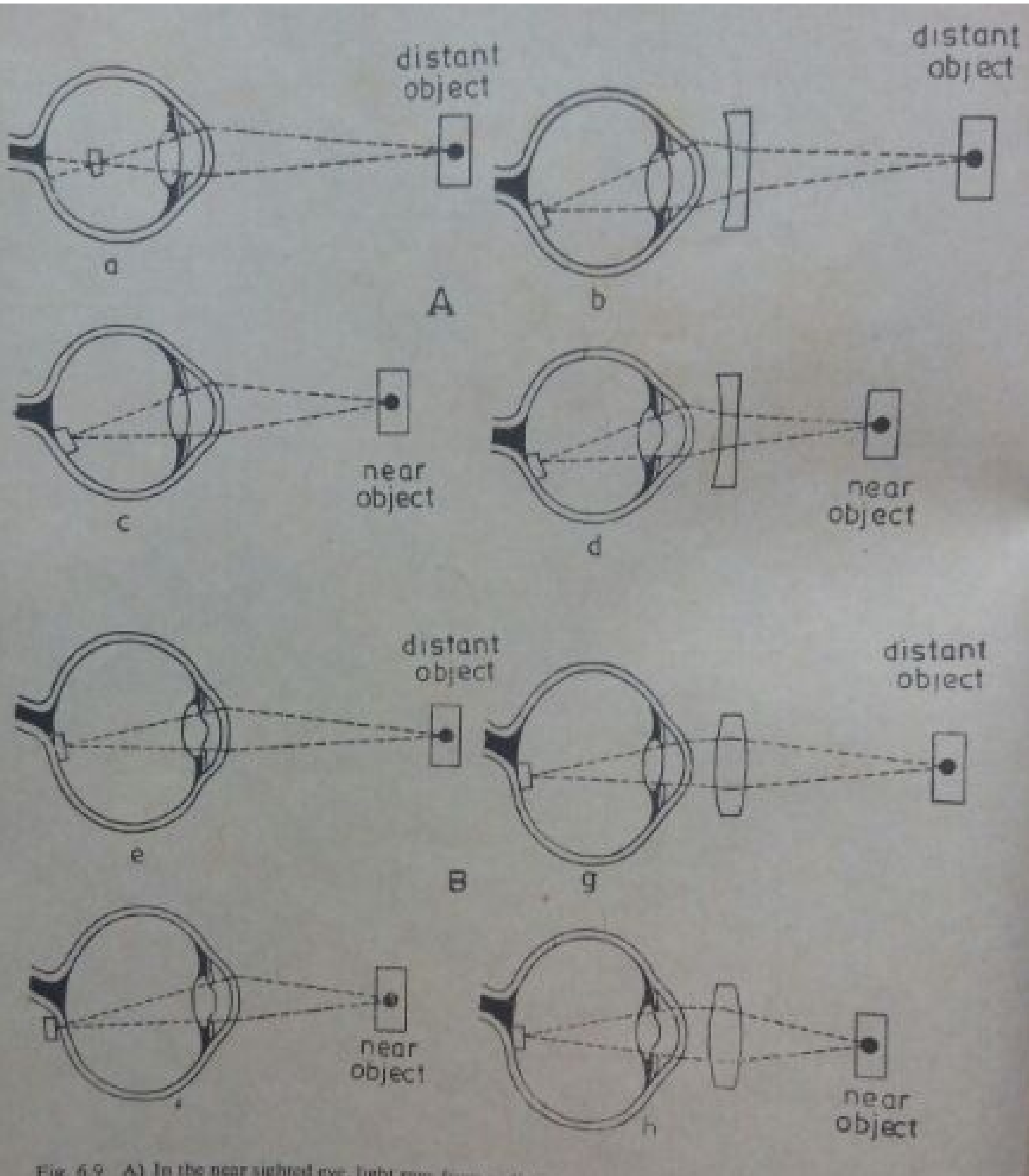


Fig 6.9 A) In the near sighted eye, light rays from a distant source are focussed in front of the retina (a)
A concave lens placed before the eye bends the light rays out sufficiently to be focussed back
into the retina (b).
When near objects are viewed through concave lenses, the eye accommodates to focus the
image on the retina (c, d).
B) The far sighted eye must accommodate to focus the image of distant objects upon the retina
The normal eye views distant objects with a flat, stretched lens. (e) The accommodating
power of the lens of the eye is sufficient for distant objects, and these objects are seen clearly
The lens cannot accommodate enough to keep images of near objects focussed on the retina
and they are blurred (f). The convex lens converges light rays before they enter the eye and
allows the eye's lens to work in a normal manner (g, h).

(ii) *Hypermatropia* or *Far-sightedness* is due to just the opposite conditions and is corrected by wearing suitable convex lenses (Fig. 6.9).

(iii) *Astigmatism* is due to irregularities in the shape of the lens and the cornea. In this defect, lens and cornea have different curvatures along different meridians of the eye. Cylindrical glasses are used to correct this defect.

(iv) *Presbiopia* or *Old-age sight* is due to the loss of flexibility of the lens and one feels difficult in focussing on nearer objects. This defect starts appearing from the age of about forty to forty-six years and is corrected by the use of convex lenses.

(v) *Cataract:* The lens becomes opaque due to several causes and requires the help of an eye-specialist (*opthalmologist*) to correct it by removal of the lens and replacement by a convex lens.

THE EAR

The ear consists of three parts: the external, the middle and the internal ear (Fig. 6.10). The external or the outermost part of the ear is a skin-covered, cartilagenous organ called *pinna*. It collects sound waves and admits them into the tubular auditory passage. Some animals can move their external ears in the direction of the sound, but such muscles are vestigeal in man, although some people do have the capacity to move their ears slightly. A waxy layer in the auditory passage entangles the bacteria and any other minute organisms that may creep in. Similarly, the fine hairs at the outer opening also have a protective function. At the inner end of the auditory passage is a delicate, obliquely placed membrane called the *eardrum*.

The middle ear consists of a set of three tiny bones which are lodged in a chamber

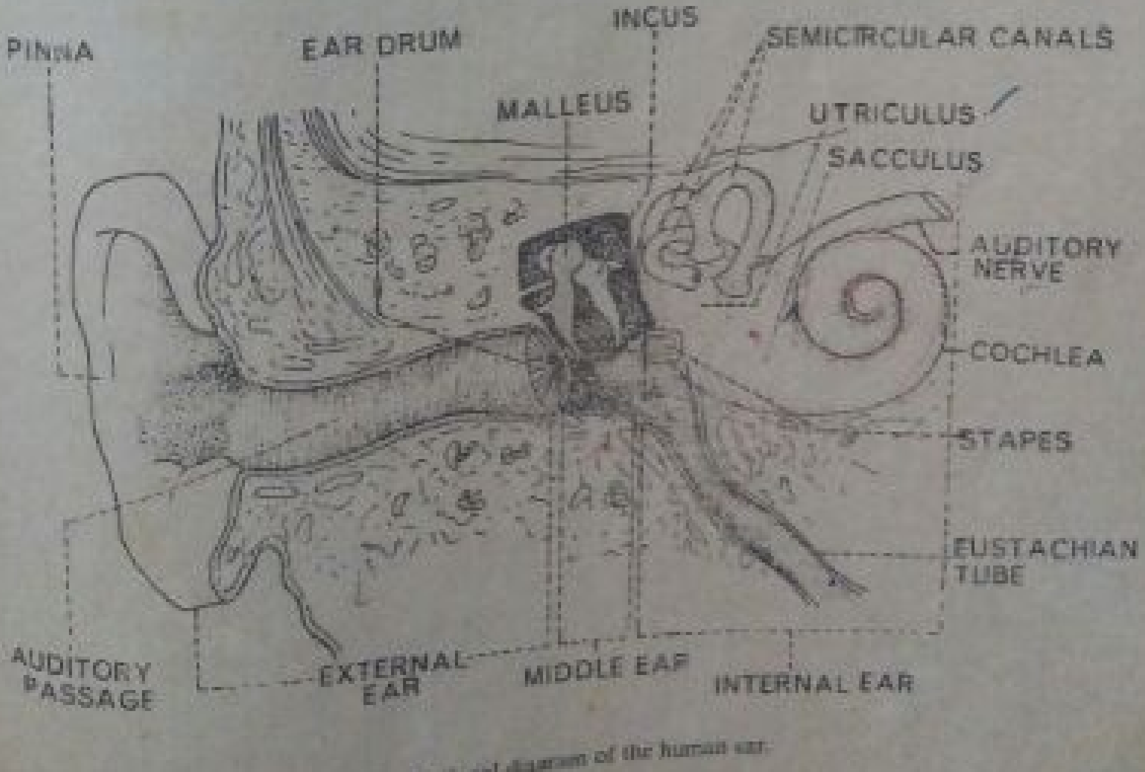


Fig. 6.10 Sectional diagram of the human ear.

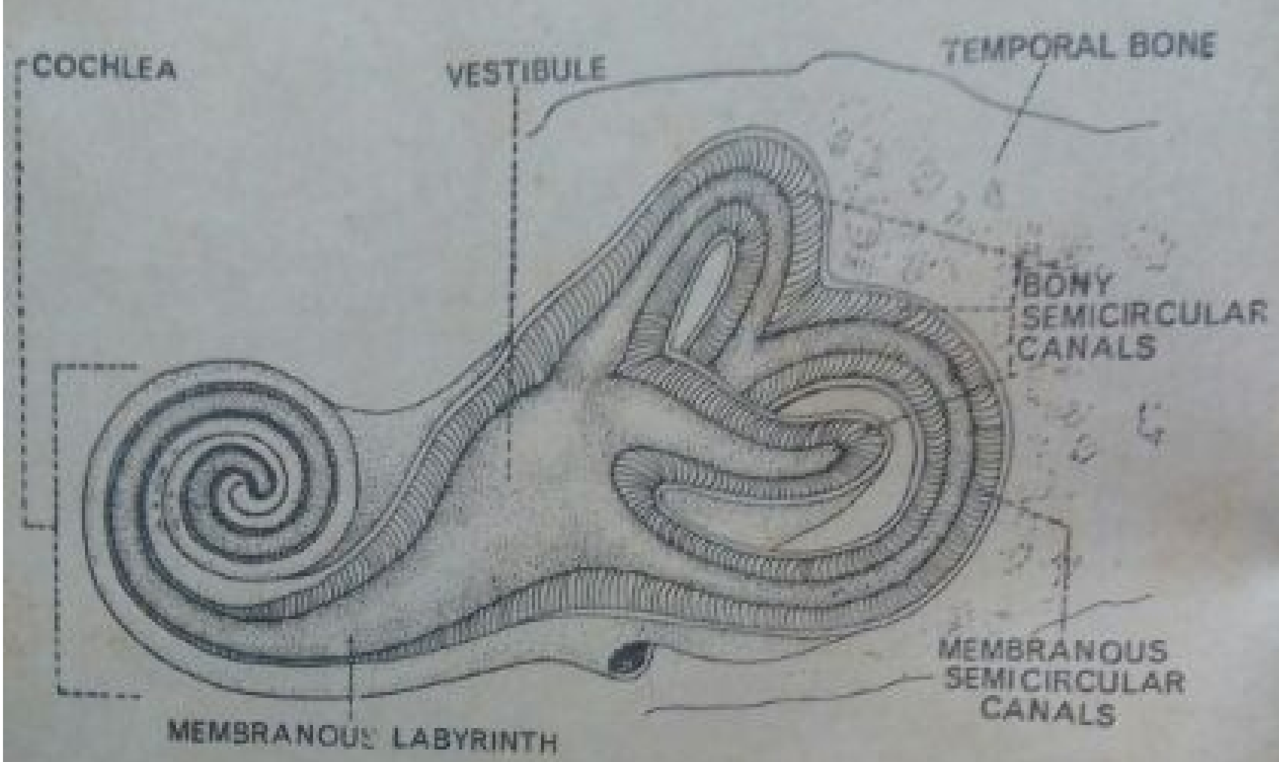


Fig. 6.11 Structure of the internal ear

The first is the *hammer* (*malleus*) attached to the inner surface of the *eardrum*; next to it is the *anvil* (*incus*), and the third is the *stirrup* (*stapes*). The inner end of the stirrup fits into an oval opening in the inner wall of the chamber. An air passage, the *eustachian tube*, connects the floor of the middle ear with the pharynx. It balances the air pressure on either side of the eardrum.

The internal ear is very delicate. It has two main regions: the upper *utriculus* and the lower *sacculus* (Fig 6.10, 6.11). The upper portion is connected with three *semi-circular canals* which are concerned with the sense of position of the body (balancing) and not with hearing. From the sacculus arises a long tubular part of *cochlea*, which is coiled like a conch shell and is embedded in a bone of the skull. It carries a system of canals and spaces which are filled with the lymph-like fluids, and there are fine sensitive membranes running across it. Branches from the auditory nerve enter these membranes. This part is concerned with the sense of hearing.

Mechanism of Hearing

When sound waves strike the eardrum, the vibrations ultimately reach the cochlea through the three bones. The fluid in the cochlea is set in motion and the auditory cells are stimulated. The movement of the fluid depends upon the frequency of the sound waves. The stimulus is carried to the brain through the auditory nerve. Just as the vibration of the wire of a violin at different places produces sounds of different pitches, here too, the auditory cells in different parts of the membrane of the cochlea are sensitive to different pitches of sound. The cells at the base of the cochlea are stimulated by sounds of high frequency while those in the upper part are stimulated by sounds of low frequency.

THE NOSE

This organ is a *chemoreceptor*, since it has cells which are sensitive to chemicals. These cells are situated in the lining of the nasal

mbers. The nerve fibres from these cells through the bones and reach the smell ion of the brain. The smell-carrying ticles from a substance, such as a rose, er the nose with the air and stimulate the sory cells.

E TONGUE

The surface of the tongue bears minute jections called papillae. Many papillae ry a large number of *taste buds*, each of ich is composed of a large cluster of taste h bearing hair like projections lying in a all depression of the surface (Fig. 6.12). e sensory nerve fibres arise from the inner ls of the sensory taste cells and form the te nerve. Food mixed with saliva enters pores of the taste buds and stimulates hair-like nerve endings. These impulses carried to the taste area of the brain ich gives one the sense of taste. The gue has taste buds which are receptive each of the basic four tastes, i.e., bitter, ur, salt and sweet. The ability or inability taste certain substances is often a here- ary character. Thus, a chemical like phenyl thiourea tastes bitter to some people but is tasteless to others.

THE SKIN OR CUTANEOUS RECEPTORS

The skin can perceive five types of sensations, e.g., heat, cold, touch, pain and pressure. The receptors for these sensations are distributed irregularly all over the skin. All these are supplied with nerves which are connected with the specific areas of the brain.

The external receptors give information to the animal about its environment by seeing, smelling, tasting, touching or hearing, so that the animal is able to adjust and coordinate its activities according to the environment. For example, when one sees a snake, one runs for protection. If the temperature of a place is too low, one moves to a warmer place. The responses to all these stimuli are voluntary, i.e., they are carried out with the knowledge of a person. These responses occur rapidly, the information is received through one set of nerves and the brain sends the messages along another set of nerves.

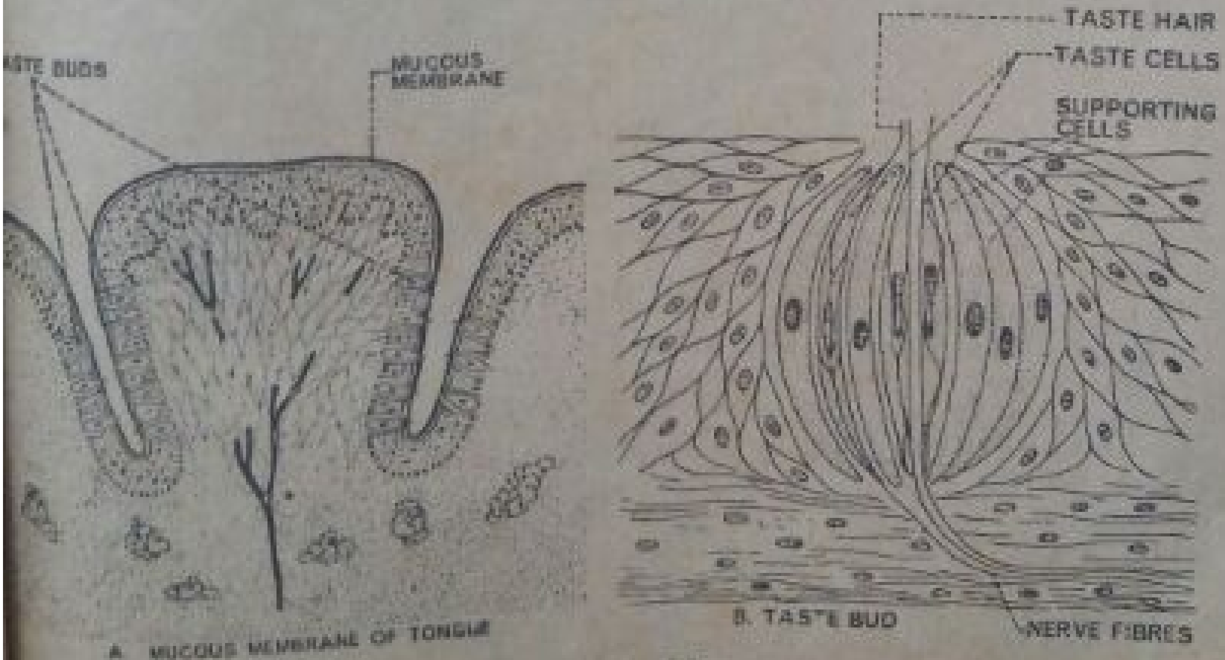


Fig. 6.12 Section of Tongue.

CHAPTER 7

Muscular System

IT may be recalled that muscles are of two major types: (i) *striated*, and (ii) *non-striated*. The striated muscles are also called skeletal muscles as they are attached to the skeletal structures (bone). Each striated muscle has two ends: (i) the point of origin which is fixed and where the muscle is attached to bone by a connective tissue, and (ii) the point of insertion which is movable and where the muscle is attached to bone by a tendon. The heart muscle is a special kind of striated muscle and is called the *cardiac muscle*. The non-striated muscle is also referred to as the *smooth muscle*. Out of these muscle types, only the skeletal muscle is under our control of will, therefore it is known as the *voluntary muscle* as opposed to the others which are *involuntary*.

Skeletal, Cardiac and Smooth Muscles

STRUCTURAL DIFFERENCES

The muscle cells are called muscle *fibres* which are cylindrical in the skeletal muscle, cylindrical and branched in the cardiac muscle and spindle-shaped in the smooth muscle (Figs. 7.1, 7.2). There are many nuclei in the skeletal muscle fibre (*multinucleated*) which are situated towards the *periphery* or edge of the fibre. The cardiac muscle fibre has one or two centrally placed nuclei, but the smooth muscle fibre has only one centrally located nucleus (*uninucleate*). Each type of muscle fibre is made up of smaller units called the *myofibrils*, the details of which can be seen only under the electron microscope. The myofibrils are formed of numerous *sarcomeres* (i.e., the distance between two Z-lines) arranged in a pile. Each sarcomere consists of regularly arranged thick and thin protein filaments constituting the *light* and *dark bands* of the sarcomere (Fig. 7.3). The dark band is called the *anisotropic band* or *A-band* and the light band as the *isotropic band* or *I-band*. The Z-band or Z-line is the dark line or membrane at the centre of each I-band. The alternate light

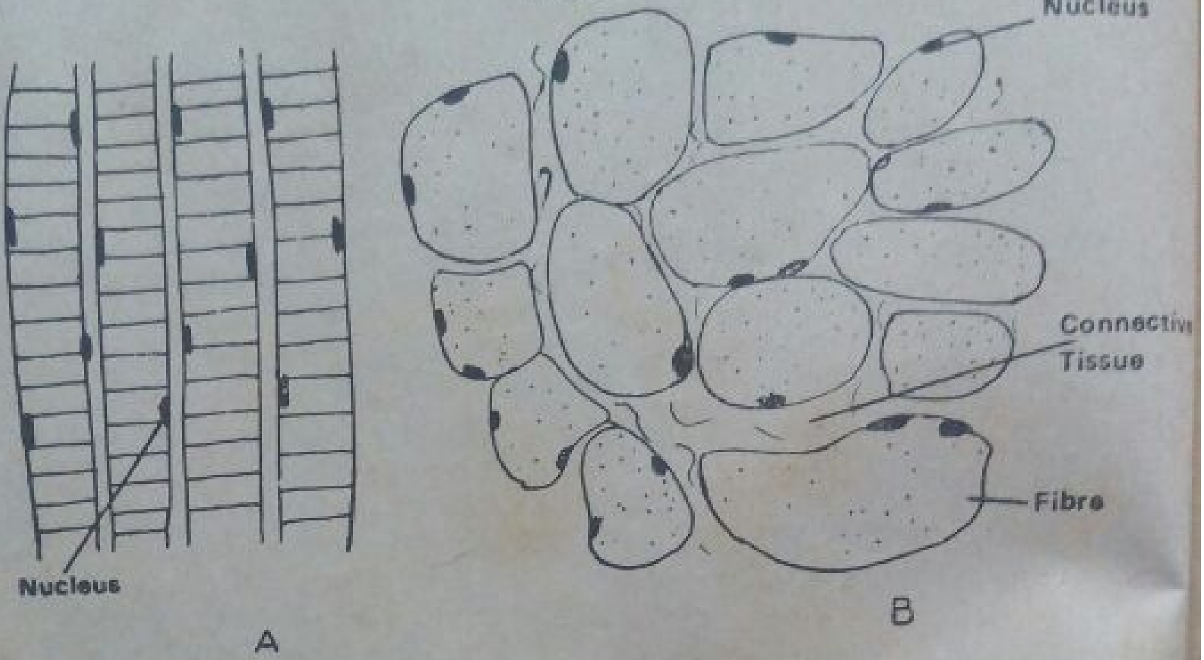


Fig. 7.1 (A) A longitudinal section and (B) a transverse section of the skeletal muscle fibres.

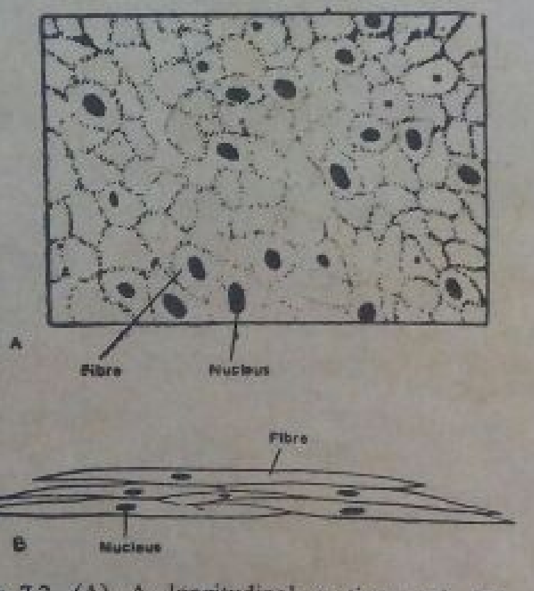


Fig. 7.2 (A) A longitudinal section and (B) a transverse section of the smooth muscle fibres.

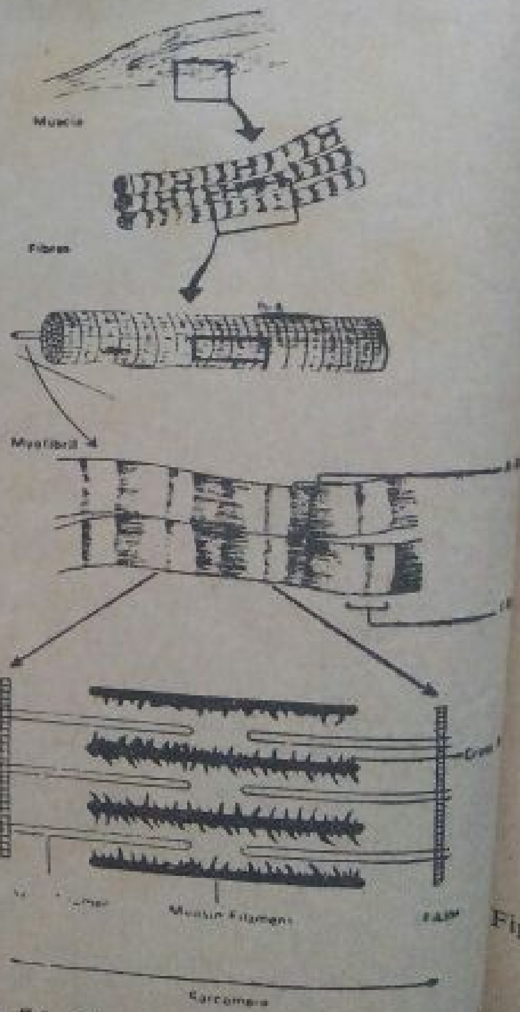


Fig. 7.3 The electron microscopic structure of fibril...

and dark bands (i.e., I and A bands) give a striated appearance to the myofibrils. The thick filaments consist of the protein *myosin* and the thin ones of *actin*. The actin and myosin help in the contraction or shortening of muscle by the formation of *cross-bridges* Fig. 7.3). The sarcomere is, thus, the functional unit of the contractile system in muscle

and the events occurring in a sarcomere are duplicated in the other sarcomeres along the myofibrils.

The smooth muscle fibres also have actin and myosin which are not aggregated into filaments and so the striations are not seen.

FUNCTIONAL DIFFERENCES

The skeletal muscle helps in the movement of different parts of the body, such as hands, legs, eyes, facial muscles, etc.

The heart muscle fibres are branched, so that its contraction can spread to all the fibres throughout the heart. *Intercalated discs* (Fig. 7.4), which are specialised regions of cell membranes of two adjacent fibres, function as *boosters* of the contraction wave and allow the wave of muscle contraction to be transmitted from one cardiac cell to another (for details, refer to Chapter 4).

The smooth muscle is found in all the visceral (body) organs, e.g., urinary bladder, stomach, intestine, uterus, etc. These muscles help in *peristalsis* or contraction of the stomach and intestine, so that the food moves down the alimentary canal; the urine is expelled from the urinary bladder and the embryo from the uterus during birth.

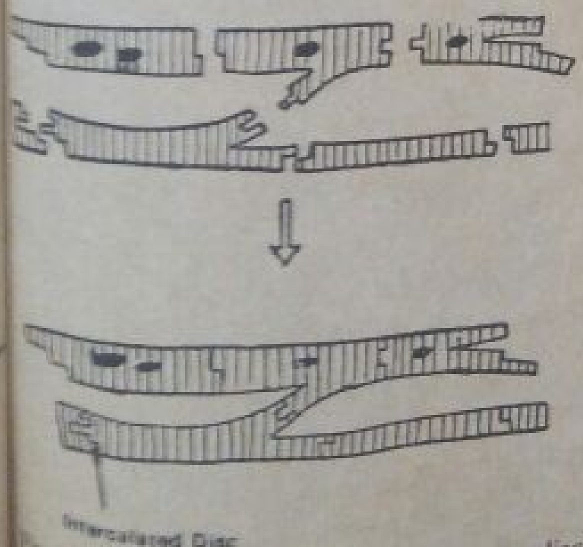


Fig. 7.4 A longitudinal section of the cardiac muscle fibers showing intercalated discs.

MUSCULAR CONTRACTION

The ultrastructural and chemical events taking place in the skeletal muscle leading to its contraction are as follows:

1. *Ultrastructural Events*

In 1954, H.E. Huxley and A.F. Huxley proposed independently the *sliding filament theory* to explain muscular contraction. The pattern of myofilaments in a muscle, after different degrees of its shortening (Fig. 7.5) was observed under an electron microscope by H.E. Huxley. He observed that as a muscle becomes shorter and shorter, the thick and thin filaments slide past each other but neither of them alters in length during shortening. Therefore, the width of the A-band remains constant. As the thin filaments slide past the thick filaments, they

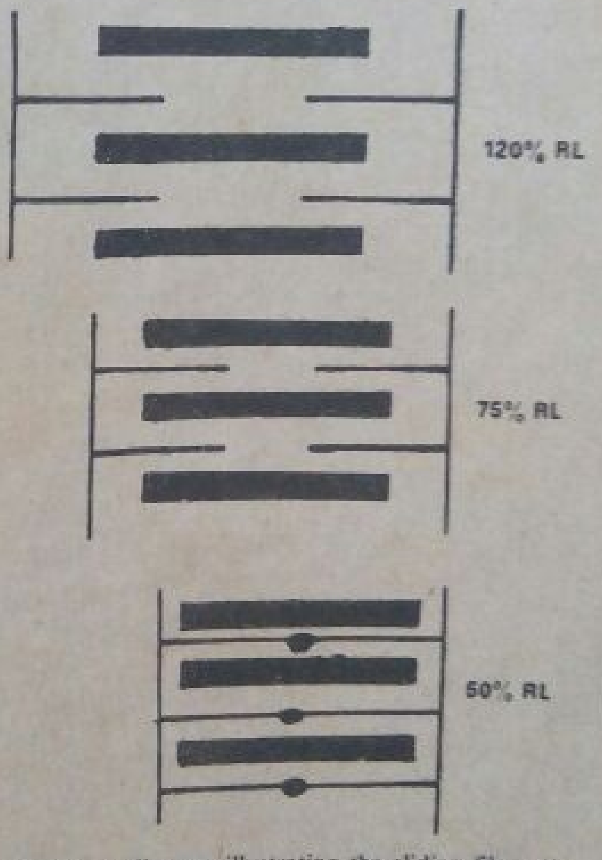


Fig. 7.5 A diagram illustrating the sliding filament theory.
RL = Relaxed length

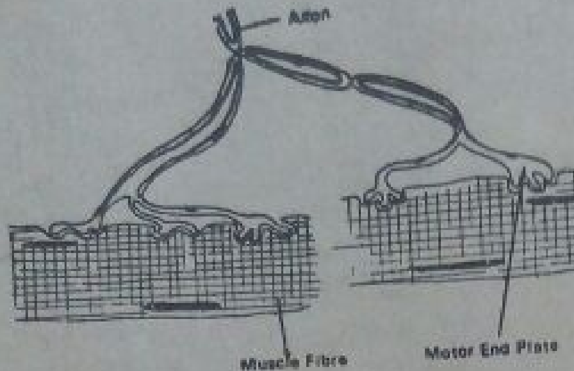


Fig. 7.6 The neuromuscular junction or motor end-plate showing the synapse between the axon and muscle fibres.

(the thin filaments) meet in the centre of the sarcomere. The I-band shortens and disappears when the sarcomere reaches the length of the thick filaments. The sliding filament theory, therefore, states that the shortening of muscles results from the relative movement of the thick and thin filaments past each other rather than from a change in the length of the filaments themselves. The actual sites of contraction are the *cross-bridges* (Fig. 7.3) which are formed where the two filaments overlap.

2. *Chemical Events*

The chemical events associated with the muscle contraction have been worked out by Albert Szent Györgyi and others.

(i) A motor nerve stimulates a muscle by the release of *acetylcholine* from the vesicles at the *neuromuscular junction* (Fig. 7.6) or motor *end plate*. Acetylcholine, in turn, evokes the release of calcium ions (Ca^{++}) from the endoplasmic reticulum of the muscle into the interior of the muscle fibre.

(ii) Myosin now binds actin to form *actomyosin* in the presence of ATP (*Adenosine triphosphate*) and Ca^{++} ions.

(iii) The enzyme *myosin ATPase*, is activated in the presence of Ca^{++} ions which breaks ATP into ADP (*adenosine diphosphate*) and phosphate (P) plus energy (E) which is used for the contraction of the muscle. Magnesium ions (Mg^{++}) are also

$$ATP \xrightarrow[Ca^{++};Mg^{++}]{ATPase} ADP+P+E$$

essential for ATPase activity and for contraction.

(iv) The muscle is rich in another high energy compound, Creatine phosphate (CP) which helps in the immediate reconversion of ADP into ATP at the end of the muscle contraction.

$$ADP+CP \rightleftharpoons ATP+C$$

(v) The muscle also has a large store of glycogen which is broken down into lactic

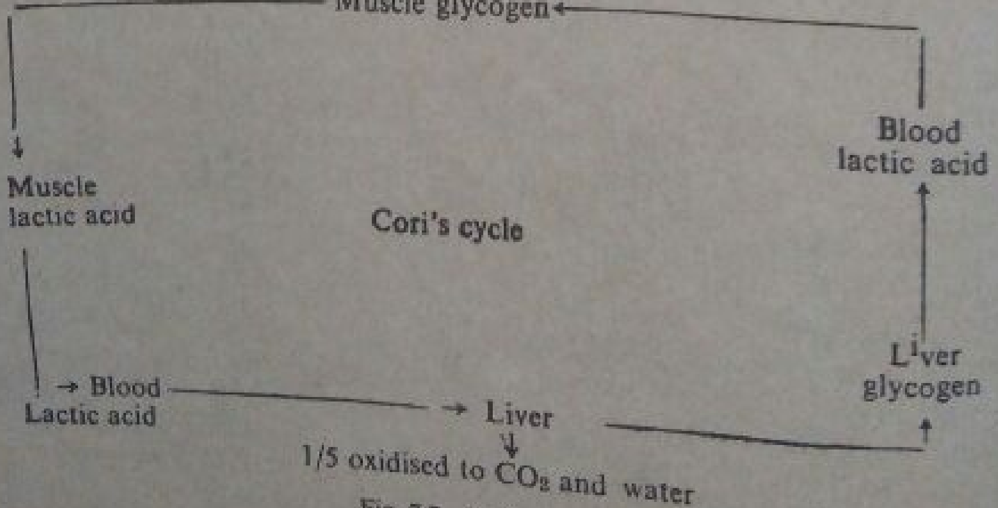


Fig. 7.7 Cori's cycle.

d by a series of reactions (*glycolysis*) and erates energy (see Chapter 2). Some of s energy is used for the reformation of and also for the conversion of 4/5ths of tic acid back into glycogen. The other 5th of lactic acid is oxidised to water and rbon dioxide (CO_2); these reactions take ace in the muscle and liver as shown in ri's cycle proposed by Cori and Cori, hose major steps are given in Fig. 7.7.

USCLE FATIGUE

How long can the muscle be maintained a prolonged contracted state depends pon the ability of the muscle to supply nergy to the contractile protein (actin and yosin) in the form of ATP. As the energy upply of the muscle is reduced, the force of ontraction decreases and eventually falls to ero. This drop in the force of contraction fter prolonged stimulation is known as uscle *fatigue*. A muscle is able to contract r a short time in the *absence of oxygen* as can use energy due to the breakdown of TP present in the muscle and from ATP synthesised from ADP by CP. Therefore, muscles are deprived of O_2, the metabolic roducts of glycolysis, mainly lactic acid, ccumulate and are not reconverted into lycogen or oxidised due to insufficient xygen supply (see Cori's cycle). The accu- ulation of lactic acid leads to *muscle tigue* due to the exhaustion of its energy serve and pain is experienced in the fati- ued muscle. The muscle fatigues sooner fter a strenuous exercise than after a mild xercise.

USCLE RELAXATION

If a muscle is to contract and relax succes- ively, ATP must be available to perform three major functions: (i) The energy re- leased due to the splitting of ATP is directly coupled to the movement of cross bridges; (ii) the binding of ATP to myosin without splitting is necessary to break the actomyosin bond and allow the cross bridge to operate; (iii) the energy released from the splitting of ATP is utilised by the *sarcoplasmic reticulum* (SR) (i.e., endoplasmic reticulum of the muscle) to trap free calcium ions and, thus, induce relaxation. There is an *active transport* of Ca^{++} ions into SR against its concentration gradient which is brought about by the utilisation of energy. For relaxation, the myosin ATPase activity has

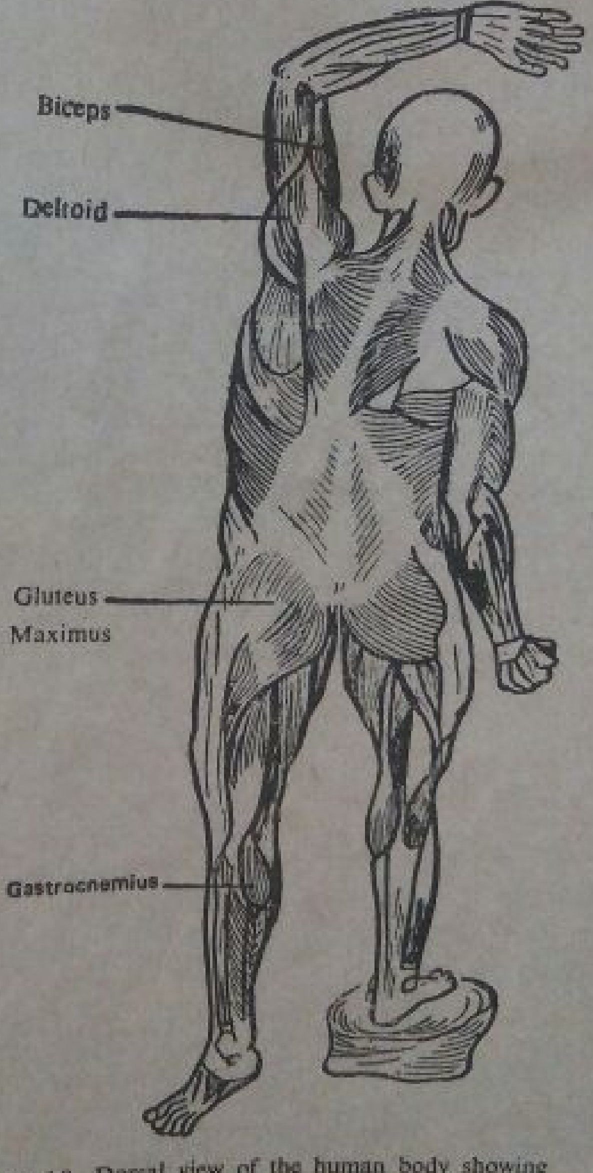


Fig. 7.8 Dorsal view of the human body showing biceps, triceps, latissimus dorsi, gluteus and gastrocnemius muscles.

to be inhibited by the non-availability of Ca^{++} ions due to its active transport in SR. Relaxation can be represented as:

$$\text{Actomyosin} \xrightarrow{\text{ATP} \quad \text{ATP}} \text{Actin} + \text{Myosin}$$

ATPase inhibited due to the absence of Ca^{++} ions and ATP cannot be broken down so that energy is not available for contraction.

Some Important Muscles of the Body

Biceps and *triceps* of the forearm: *gastrocnemius* of the shank of the leg; *glutei* of ischial calosities (buttocks): the *rectus* and *oblique* eye muscles; *maxillaries* of the upper jaw; *pectoralis major* and *minor* of the chest; *mandibularis* of the lower jaw; *Latissimus dorsi* of the shoulder; *external oblique*, *internal oblique*, *transversus* and *rectus abdominis* of the lower abdomen (Fig. 7.8).

ABNORMALITIES OF MUSCLES

(i) The adult muscle fibre, if damaged, cannot be replaced through a cell division of the surviving muscle tissue, but the surviving cells can increase their size by synthesising myofibrils within each cell. The increase in the size of individual muscle fibres is known as *muscular hypertrophy*.

(ii) As muscle contraction is normally initiated by motor nerves, any damage to the nerve cell or its axon results in the *paralysis* of the muscle. The denervated muscle decreases in size and undergoes *denervation atrophy*. A muscle can also atrophy with the intact nerve supply if it is not used for a long time, as when a broken arm or leg is immobilised in a plaster cast. This is known as *disuse atrophy*.

(iii) Any diseased condition of the muscle wherein either the nerve supplying a muscle or the muscle itself is affected is called *muscular dystrophy*. One of them is the inherited *duchenne dystrophy*. In *poliomyelitis* muscle weakness prevails due to the polio virus. Dr. Salk of the USA has developed the polio vaccine to treat the children suffering from polio.

EXERCISES

1. Describe the structural differences between smooth, cardiac and skeletal muscle.
2. What are cross bridges, actin, and myosin? Also state their importance.
3. What happens to the leg muscle of an athelete who runs a marathon race?
4. What is the role of Ca^{++} and ATP in muscle contraction?
5. What is the importance of Cori's cycle?
6. How does a muscle relax? Does the heart muscle relax?
7. Point out the location of biceps, triceps, gastrocnemius, pectoralis and abdominis muscles.
8. What is a tendon?
9. What do you understand by denervation atrophy, disuse atrophy and poliomyelitis?

Skeletal System

The skeletal system comprises the different bones in the body. The skeleton gives shape to the body and protects the important internal organs like the heart, lungs, brain, etc. The bones also help in the attachment of muscles and provide suitable leverage for locomotion. The bone marrow found in the hollow cavity of long bones (see Chapter 1) produces red blood cells.

The bones of children contain large quantities of organic substances but a small quantity of salts. Therefore, the bones of a child are more flexible and less brittle than those of an adult. That is the reason why fractures seldom occur in children. With the advance in age, calcium phosphate is deposited in the bones whose content of organic substances diminishes. The bones become harder and brittle. Thus, old people are more liable to fracture of their bones. There are more than 200 bones in the skeleton of the body of a human being.

The skeleton can be divided into the *axial* and *appendicular skeleton*. The axial skeleton consists of the *skull, vertebral column, sternum*

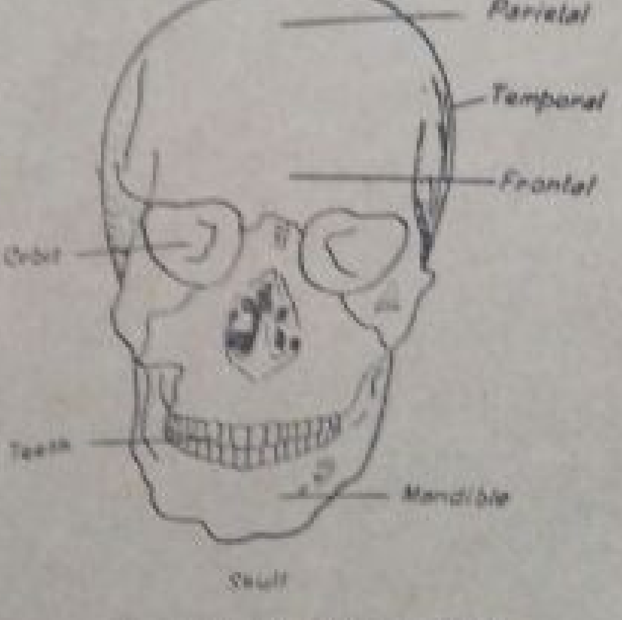


Fig 8.1 The human skull (front view).

and *ribs*. The appendicular skeleton is made up of the *girdles* and *limb bones* (Fig. 8.2).

The Skull

The skull has two main divisions: the *cranium* or the brain case and the bones of

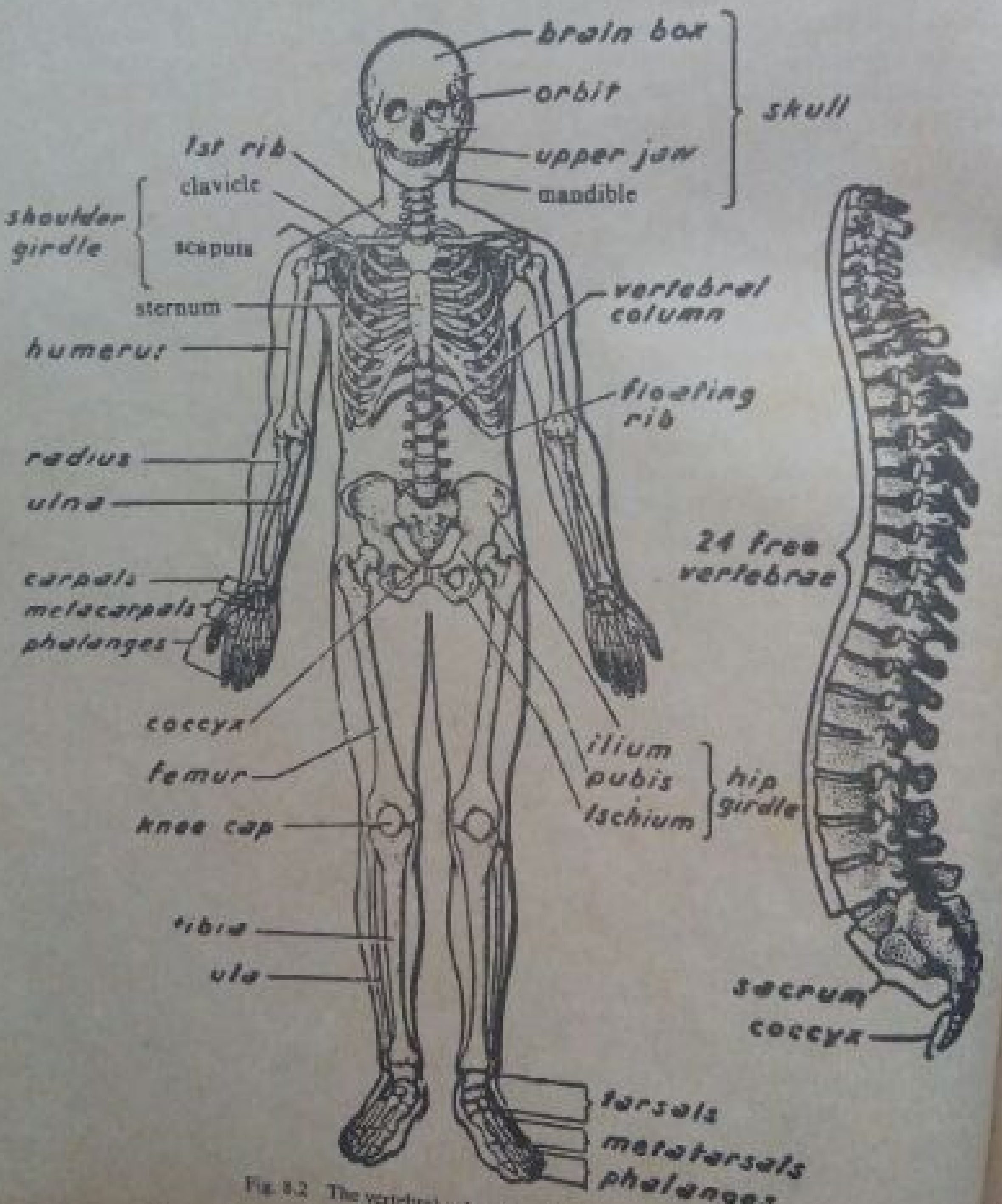


Fig. 8.2 The vertebral column viewed from the

the face. There are several flat, curved bones which are joined by *sutures*. In the adult, these bones are tightly locked together, but in a baby, they are soft and incompletely united. The cranial bones enclose the cranial cavity which opens posteriorly through an opening called *foramen magnum*. In the cranial cavity lies the brain. There are 14 bones of the face but only the lower jaw is movable. The skull has *frontal*, *parietal* and *temporal* regions. The eyes are situated in deep sockets called *orbital fossae*.

The Vertebral Column

The vertebral column is composed of 33 vertebrae (Fig. 8.2), out of which 24 are free vertebrae, followed by a *sacrum* made of five fused vertebrae and a *coccyx* made of four fused bones, forming the vestige of the tail.

Five regions can be recognised in the vertebral column. The *neck or cervical region* is made up of seven *cervical vertebrae*. The first and the second cervical vertebrae are called the *atlas* and *axis*, respectively.

The *thoracic region* consists of 12 thoracic vertebrae. The abdominal region has five vertebrae which are large and heavy and are called the *lumbar vertebrae*.

The pelvic or hip region (*sacral*) consists of five sacral vertebrae which are fused to form the *sacrum*.

The tail or *coccygeal region* has four small vertebrae which are fused to form the tail bone.

The vertebra of each region is distinct in its structure. However, in general, a vertebra has a ringlike hole through which passes the spinal cord. It also has paired processes, the *pre* and *post-zygapohyses* and the *transverse processes*. In between two vertebrae is the *intervertebral disc*, which if displaced from its position results in the *slip-disc*.

Bones of the Chest or Thorax

The bones of the chest form a thoracic basket (Fig. 8.3) which encloses and protects the heart and lungs. In the middle of the front portion of the thorax lies the *sternum* or the breast bone. The sides of the chest cavity are formed of 12 pairs of *ribs*. The first seven pairs of ribs are attached to the thoracic vertebrae at the back and to the sternum in the front. The next three pairs are connected to the rib above each. The last two pairs are free and are called the *floating ribs*. This arrangement allows the chest to expand and contract during breathing movements.

The Girdles

The bones of the limbs are attached to the girdles. The bone of the forelimb is attached to the *pectoral* or *shoulder girdle* situated at the upper part of the body. The thigh bone is attached to the *pelvic* or *hip girdle* situated at the lower end of the body. The pectoral girdle is made up of the *clavicle* and the *scapula*. There is a *glenoid cavity* into which the head of the humerus fits (Fig. 8.4).

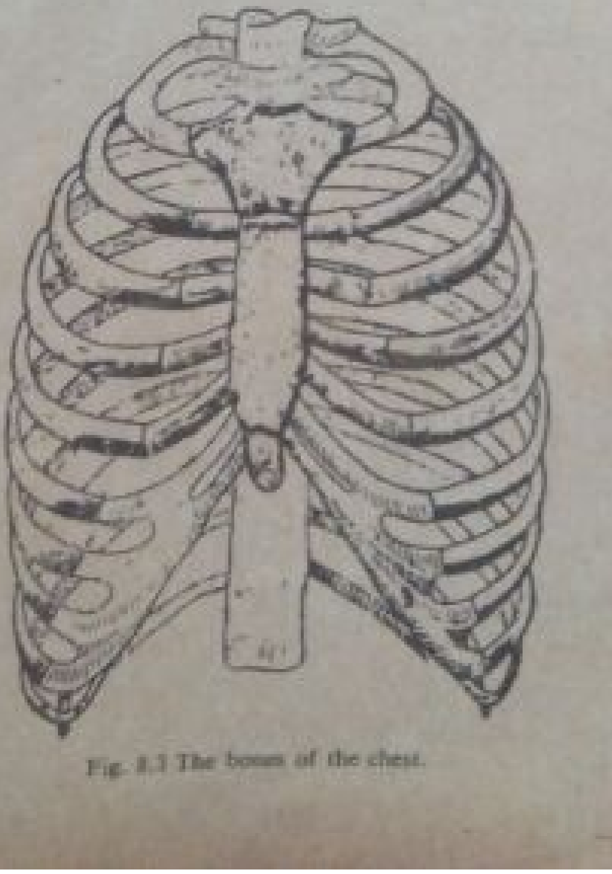


Fig. 8.3 The bones of the chest.

The pelvic girdle of each side has the large *ilium*, *pubis* and *ischium*. The head of the femur fits into the cavity called *acetabulum* (Fig. 8.5).

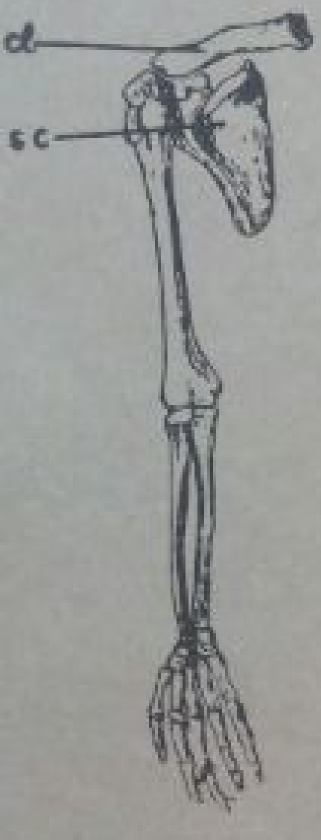


Fig. 8.4 The pectoral girdle of man with bones of the hand. Cl. Clavicle; Sc. Scapula.

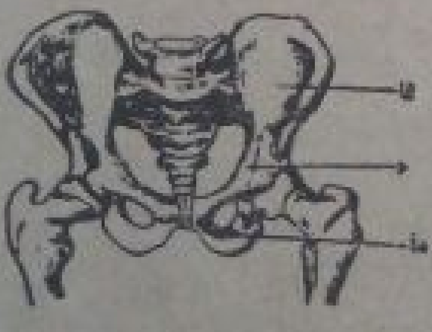


Fig. 8.5 The pelvic girdle of man. I. Ilium; P. Pubis; Is. Ischium.

Bones of the Hand and the Leg

The upper arm has a single bone, the *humerus*, the forearm has the *radius* and *ulna* (Fig. 8.6). In the wrist, there are eight small bones called the *carpals*. The palm is made up of *carpals* and *metacarpals* and each finger is supported by three small *phalanges*. Except the thumb which has only two phalanges. The skeleton of the leg is similar to that of the arm (Fig. 8.7). The femur of the thigh bone is the largest bone of the leg. Its upper end is ball-shaped and fits into the socket of the pelvic girdle. The knee cap is protected by a flat triangular bone, *patella*. The lower leg is formed of the *tibia* and *fibula*. The ankle bones are the *tarsus*, followed by the foot bones or *metatarsus*, and finally the *phalanges* of the toes.

Articulation of Bones—Joints

The place of contact between two or more bones is a *joint*. Depending on their structure,

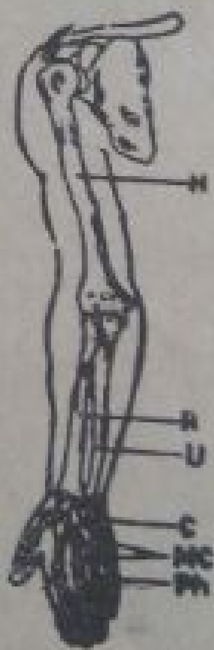


Fig. 8.6 Bones of the hand of man. H. Humerus; R. Radius; U. Ulna; C. Carpal; Mc. Metacarpal; Ph. Phalanges.

joints permit differing degrees of movements of bones.

1. *Fibrous joints* are *immovable or fixed joints* and the bones articulating at such a joint cannot change position relative to each other, because dense bundles of tough and strong white collagenous fibres hold the bones closely and firmly together at the joint and elasticity essential for joint movements is absent in such white fibrous tissue. Joints in tooth sockets and between skull bones are fibrous joints (Fig. 8.9A).

2. *Cartilaginous joints* are *slightly movable joints* (Fig. 8.9B). Discs of white fibrocartilage, strong but more elastic and compressible than the white fibrous tissue, hold the bones together at the joints between the bodies of vertebra, at the symphysis pubis, and between sternum and ribs. The bones make some movements at such joints through compression of the discs of cartilage.

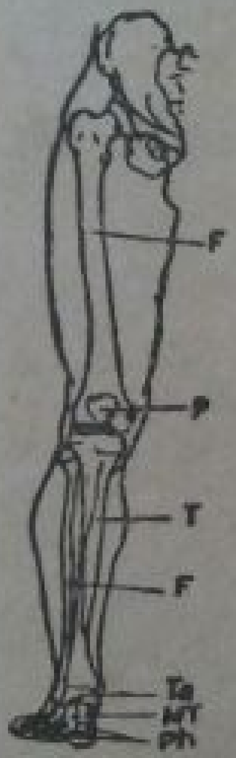


Fig. 8.7 Bones of the leg of man. F. Femur; P. Patella; T. Tibia; F. Fibula; Ta. Tarsus; Mt. Metatarsus; Ph. Phalanges.

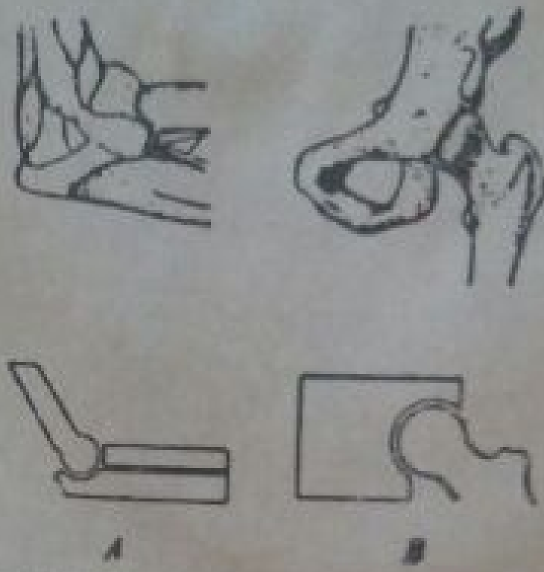


Fig. 8.8 Joints: (A) Hinge joint. (B) Ball and socket joint;

3. *Synovial joints are freely movable joints* (Fig. 8.9C) and are present at the elbow, ankle, hip, wrist and knee. Here, the articulating urfaces of the two bones are covered with a smooth piece of hyaline cartilage each, and the space (joint cavity) between the ends of the two bones is filled with slippery *synovial fluid* and is lined by a *synovial membrane*. The cartilages and the synovial fluid permit easy and smooth bone-movements at such joints. Synovial joints may be of different types, according to the nature of articulation and degree of movement (Fig. 8.9). (a) *Ball and socket joints:* Here, the ball of one bone fits into the socket of another, as it makes movement possible in all directions, bending and stretching movements from side to side and rotation (Fig 8.8B) (b) *Hinge joints:* These are found in the elbow, knee and fingers, the ends of the bones fit into each other in such a way that movement is possible in one direction only, e.g., flexion and extension (Fig. 8.8A).(c) *Angular joints:* In joints like the wrist and the metacarpophalangeal joints, movement is possible around two axes. (d) *Pivot joints:* In this kind of joints, turning or rotatory movement is possible around one axis only, as in the case of the skull rotating on

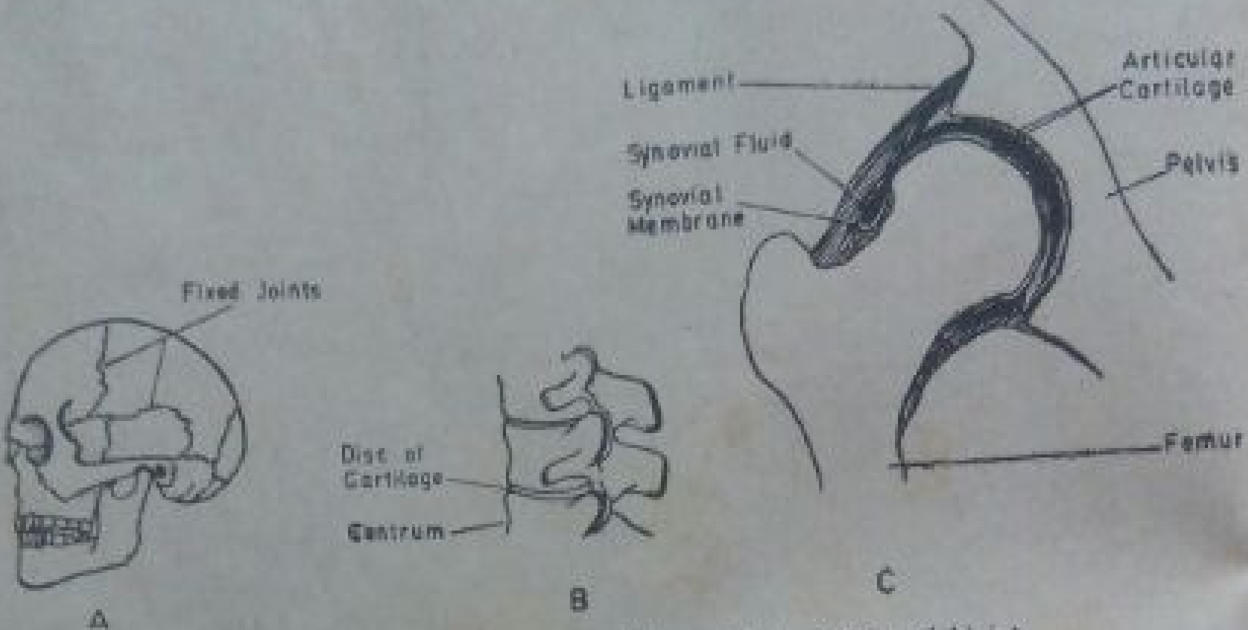


Fig. 8.9 A) Fixed joint, B) Cartilaginous joint, C) Synovial joint.

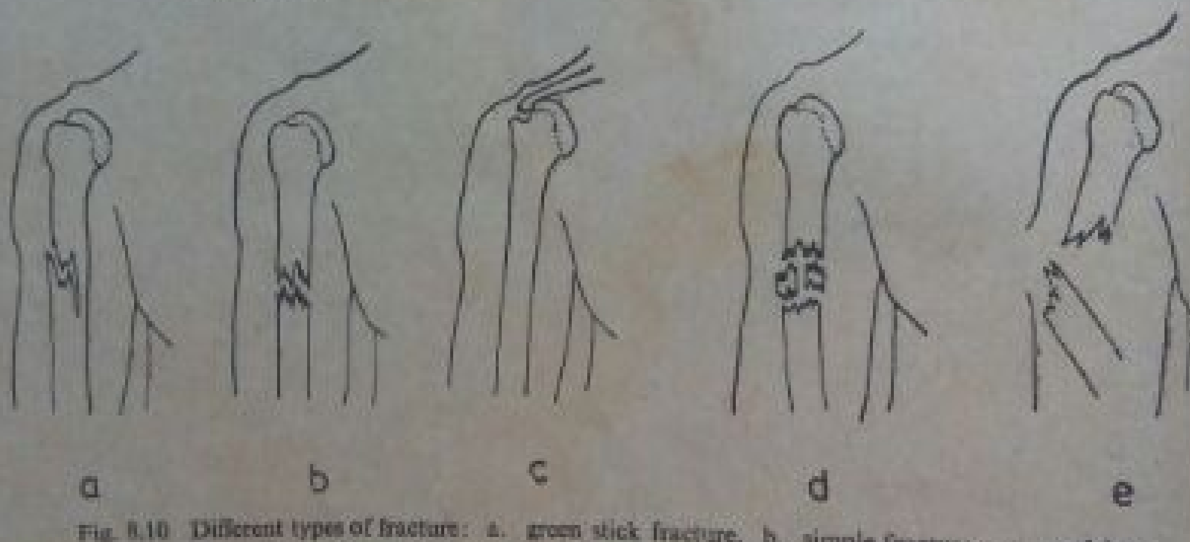


Fig. 8.10 Different types of fracture: a. green stick fracture, b. simple fracture, c. evulsion fracture, d. comminuted fracture, e. compound fracture.

the vertebral column and the joint between radius and ulna. (c) *Gliding joints:* In joints between tarsal bones in the ankle, carpal bones in the wrist, and between sternum and c'avicle, the end of one bone glides across a certain portion of the surface of the other bone.

Dislocation and Fracture

Any violent careless movement, a jump, fall or knock, may result in an injury to the skeleton. The injury may be a *dislocation* o a *fracture*.

In the case of a dislocation, the bones the joint are dislodged from their positio e.g., the ball of one bone may slip out of t socket, tearing the ligaments apart.

A *fracture* is a break of the bone (Fig 8.1 (a) A break of the bone in the form of on crack, with the broken parts still holding gether, *is a green stick fracture* (Fig. 8. (b) A fracture breaking the bone into two

separate parts not displaced much from their positions and still lying close to each other, is a *simple fracture*. (c) It is an *evulsion fracture* when a part of the bone has been broken off from the main body of the bone and remains still attached to the ligament. (d) In a *comminuted fracture*, the bone is broken into more than two fragments with some of the fragments probably losing any connection with blood circulation. (e) when the bone is so fractured that a fragment of the bone protrudes out through a breach in the skin, it is a *compound fracture*.

EXERCISES

1. What are the parts of the skeletal system?
2. What is the utility of the ribs in the body?
3. Which part of the skeleton protects the brain?
4. What are the regions of the vertebral column?
5. What is the function of the girdles?
6. Where are the glenoid cavity and acetabulum found? What is their use?
7. Give examples of the ball and socket joint, the hinge joint, the angular joint the gliding joint and the pivot joint.
8. What is dislocation and fracture of a bone?
9. Which bones have marrow?
10. What are fibrous, cartilaginous and synovial joints. Give example?

CHAPTER 9

Endocrine System

Endocrine Glands

THE *endocrine glands* or *ductless* glands produce chemical substances which they secrete directly into the blood for transport to their organs or tissues. These secretions, called hormones, catalyse and control diverse metabolic processes. Hormones are catalysts, required only in very small amounts and are not used up during their catalytic action. They are produced in an organ other than that in which they ultimately perform their action. They are secreted into the blood which transports them to the site of their action Thus the circulating levels of the hormone indicate the activity of an endocrine gland. The blood levels of hormones can be extremely low because only small amounts of hormones are required. Structurally, hormones are not always proteins. They may be polypeptides, steroids, amino-acid derivatives or biogenic amines. *Protein hormones* or *peptide hormones* are those produced by the hypothalamus, pituitary, parathyroids and pancreas, besides one hormone of the ovary (relaxin) and another of the placenta (human chorionic gonadotropin).

Steroid hormones are produced by the adrenal cortex, ovaries and testes. *Biogenic amines* are produced by the pineal gland and the adrenal medulla. The thyroid hormone called thyroxine is an iodinated derivative of an amino-acid.

The hormones produced by endocrine glands serve as chemical messengers and are carried by the blood to the target organs where they regulate a variety of physiological and metabolic activities.

The various endocrine glands and their location are shown in Fig. 9.1. The functions of the various glands, like the thyroid, adrenal, ovary and testis, are regulated by the hormones secreted by the pituitary gland. The secretions of the hormones from the pituitary gland, in turn, are regulated by the hormones of the hypothalamus. The primary target for the hypothalamic hor-

the pituitary gland. The hormones of pituitary influence other endocrine glands which may be called the secondary targets of hypothalamic hormones. The hormones of the secondary target glands may influence, in their turn, the final target organs.

Hormone action. The effects of a hormone on a cell in the target organ are mediated by the stimulation of synthesis of specific proteins or other secretory products. Specific recognition sites (receptors) for a particular hormone are present either on the cell membrane or in the cytoplasm and nucleus of the cell and the hormone reacts with its specific receptor in the target cell to stimulate or influence the latter.

The location (Fig. 9.1), structure and functions of some of the endocrine glands are given below.

The Pineal Gland

Till recently, it was believed that the pineal gland found in the midbrain area was a vestigial organ without any useful function. It is now known that the pineal produces several hormones. One of them, *melatonin*, is not a protein. It is antigonadal as it may delay sexual development and may reduce the reproductive activity. In Amphibia, melatonin makes the skin more pale. Melatonin is synthesised from another amine called serotonin which helps to decrease the diameter of blood vessels (*vasoconstrictor*).

Thyroid Gland

The thyroid gland is found on the ventral side in the neck region at the base of the larynx. It produces a hormone, *thyroxine*, which is an iodinated amino acid. This hormone stimulates the rate of cellular oxidation and metabolism to produce more energy and heat (*calorigenic effect*). It also stimulates *growth and differentiation of tissues* in many animals. Excessive secretion of thyroxine from thyroid (*hyperthyroidism*) increases cellular metabolism. The body

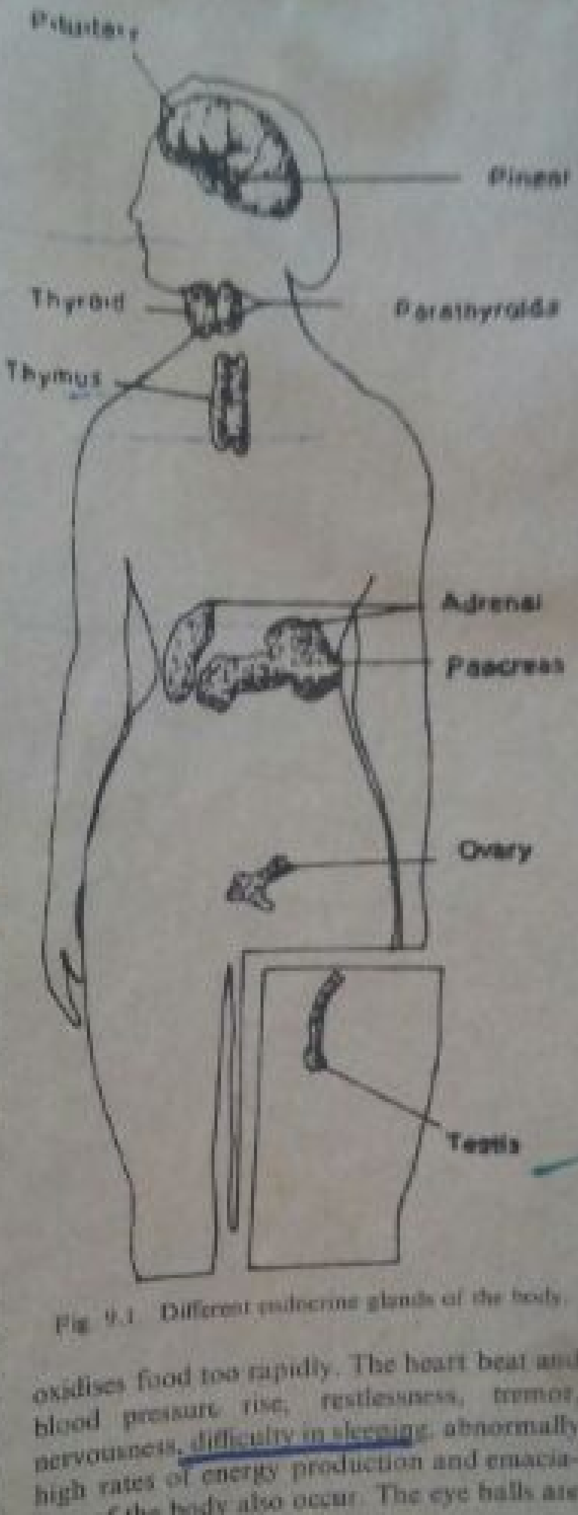


Fig. 9.1 Different endocrine glands of the body.

oxidises food too rapidly. The heart beat and blood pressure rise; restlessness, tremor, nervousness, difficulty in sleeping, abnormally high rates of energy production and emaciation of the body also occur. The eye balls are found to protrude in the patients.

In underactivity of the thyroid (*hypothyroidism*) in adults, thyroxine secretion is

reduced, oxidation of food, tissue metabolism and energy production are depressed, heart beats are slowed, and the person gets a puffy appearance. This disease is known as *myxoedema*. In children, hypothyroidism produces in addition, a failure of physical, mental and sexual growth and maturity (*cretinism*); the patient is stunted and of low intelligence. *Simple goitre* results due to the deficiency of iodine, a constituent of thyroxine. In this type of goitre, the thyroid enlarges in an effort to produce more thyroxine, but hypothyroidism may still continue due to iodine deficiency. Addition of iodides to the table salt prevents this disease.

Another hormone, calcitonin, of the thyroid is a protein. It reduces the blood calcium level.

Parathyroids

Parathyroids are four small glands, two on each side of the dorsal surface of the thyroid. Their hormone, *parathormone* or PTH, is a protein hormone. It increases the blood calcium level by mobilising calcium from bone to blood and also by lowering urinary excretion of calcium. A deficiency of PTH secretion lowers the blood calcium and consequently increases the excitability of nerves and muscles abnormally (parathyroid tetany). Excessive secretion of PTH from parathyroids causes a fall in bone minerals leading to a softening, bending and fracture of bones, raises the blood and urinary levels of calcium and produces calcification of soft tissues like blood vessels (osteitis fibrosa cystica). Thus PTH influences blood calcium, bone calcium and also neuromuscular excitability.

Parathyroids may also secrete some calcitonin (see Thyroid gland).

Pancreas

Pancreas has both exocrine and endocrine portions (see chapter 2). The exocrine part secretes the digestive juice called the pancreatic juice (chapter 2). The *islets of Lan[gerhans]* form the endocrine part; α-cells of [the] islets secrete glucagon and β-cells sec[rete] insulin, both being protein hormones.

Insulin regulates the amount of sugar [in] the blood and controls the metabolism [of] carbohydrates in the body. It lowers [the] blood glucose level by increasing the util[isa]tion of glucose in the tissue cells and [the] storage of glucose as glycogen in the tiss[ues]. If the pancreas do not secrete suffic[ient] amounts of insulin, the liver and muscles [are] unable to convert the excess glucose of bl[ood] into glycogen (glycogenesis) and glu[cose] utilisation for energy production or [energy] production is also reduced; so, more [and] more of glucose collects in the blood (hy[per]glycæmia) and the excess of glucose in [the] blood is also eliminated in the urine (gly[co]suria). This disease is called *diabetes melli[tus]*. [The] injection of insulin into the patients low[ers] the blood sugar. Excessive of insulin i[n a] person cause an abnormal lowering of bl[ood] glucose (hypoglycemia).

Glucagon is opposite in effect. Gluc[agon] increases the conversion of liver glycog[en to] glucose (glycogenolysis) and this glu[cose] enters the blood to raise the blood s[ugar] level.

Renin-Angiotensin System

Near the glomeruli in the cortex or [outer] part of kidney are juxtaglomerular [cells] which are believed to secrete a protein [called] renin under the influence of nervous [stimuli] and other factors. It helps to change a p[lasma] protein, angiotensinogen, to peptide [called] angiotensin. The latter stimulates the a[drenal] cortex to secrete a hormone called al[dos]tone. Angiotensin also causes vasocon[stric]tion to raise the blood pressure. An[giotensi]nogen is produced in the liver (Fi[g. ...]

Adrenal Gland

There are two adrenal or sup[rarenal] glands, one on the top of each kidn[ey]

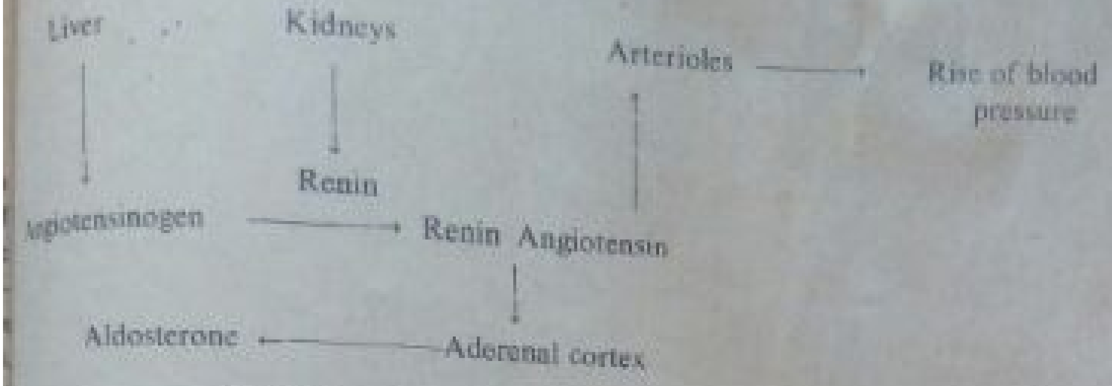


Fig 9.2 Renin-Angiotensin system.

ter part or cortex of each adrenal produces a number of steroid hormones, derivatives of cholesterol. Those steroids of adrenal cortex which influence metabolism of carbohydrates and proteins are called *glucocorticoids*, e.g. cortisol and cortisone. They increase the blood glucose level by increasing formation of carbohydrates from protein (gluconeogenesis) and also by increasing the conversion of glycogen to glucose in the liver (glycogenolysis). Some other steroids of this gland influence salt and water metabolisms and are called *mineralocorticoids*, e.g. aldosterone. They reduce sodium loss from the body in urine, sweat, saliva, etc., increase simultaneously the excretion of potassium, retain water in the body along with sodium and so, maintain salt and water balance. Some other cortical steroids called *sexcorticoids* influence external sex characters.

The central part or medulla of each adrenal secretes two amines, *epinephrine* (or adrenaline) and norepinephrine (or noradrenaline). They regulate the blood pressure, heart beat, respirations, contractions and relaxations of smooth muscles, and other activities controlled by the sympathetic nervous system. Epinephrine also increases blood glucose level, oxygen consumption, and heat production. This hormone prepares the individual for meeting emergency or stress. During stress, epinephrine is secreted and it produces increased blood pressure, rapid and stronger heart beats, and a release of more sugar from the liver to the blood (glycogenolysis) to provide more material for increased oxidation.

Gonads—Ovary and Testis

Females have two ovaries, one on each side of the lower part of the abdomen. Ovaries produce eggs (ova) and secrete the female sex hormones, *oestradiol* and *progesterone*, both steroids. These hormones regulate at puberty the growth and development of secondary female sex organs like the uterus and mammary glands and of *female accessory sex characters* like deposition of fat on thighs and the female pattern of pubic hair distribution. They also maintain the normal functions of the secondary sex organs and control their changes during menstrual cycle (see chapter 10) and pregnancy. The peptide hormone relaxin of ovary makes child birth easier by softening the plevic ligament.

In the male, two testis are found in the scrotal sac between the thighs. The scrotal sac, in which the testis hang outside the abdomen, maintains them at a temperature 2°C lower than the rest of the body. This is necessary to enable the testis to produce sperms (spermatogenesis). The testis also secretes the male sex hormones called androgenic hormones which are all steroids; the principal testicular androgen is testosterone. At puberty, testosterone stimulates the

growth and development of male secondary sex organs like prostate and seminal vesicles and also of male accessory sex character like the deepening of the voice, broadening of shoulders and the male pattern of distribution of pubic hair. It also maintains the male secondary sex organs and their functions in the adult male.

Thymus

It is situated behind the sternum. It secretes thymosin, a protein hormone, which probably stimulates the proper differentiation of lymphocytes in the foetus and the new born child.

Pituitary

Until recently, the pituitary gland was considered to be the chief gland of the endocrine system. It is known now that the pituitary itself depends for its activity on the hormones received from the hypothalamus (hypothalmic *neurohormones*). The hypothalamus is a nervous structure situated at the base of the brain. The pituitary hangs below the hypothalamus. The pituitary has three parts, viz., anterior, intermediate and posterior lobes. Each part secretes different hormones. The anterior pituitary is connected with the hypothalamus by a portal system of blood vessels (hypophysial portal vessels) while the posterior pituitary is connected with the hypothalamus by nerve fibres.

The hypothalamus secretes several different neurohormones, called releasing hormones (RH), which are small peptides and are carried to the anterior pituitary through the portal blood vessels. These neurohormones regulate the synthesis and release of different hormones of the anterior pituitary (Table 9.1). The six hormones of anterior pituitary are proteins and are as follows. The *adrenocorticotropic hormone* (ACTH) stimulates the adrenal cortex to secrete glucocorticoids; mineralocorticoid secretion from the adre[nal] cortex is stimulated only to a much sma[ller] extent by ACTH. The thyroid stimula[ting] hormone or thyrotropin (TSH) stimula[tes] the thyroid gland to secrete thyroxine. T[he] growth hormone (GH) stimulates the grow[th] of tissues, particularly long bones a[nd] muscles, and may counteract insuline to ra[ise] the blood sugar level. Failure of GH secreti[on] from childhood makes the child a dwa[rf] excessive secretion of GH from infancy [or] childhood causes overgrowth of long bo[nes] making the patient too tall (giganti[sm]). Three hormones viz, follicle stimulati[ng] hormone (FSH), *Luteinising hormone* (L[H]) and *prolactin*, influence the gonads, [and are] collectively known as *pituitary gonadotrop[ins]*. Prolactin helps in the growth of mamm[ary] glands during pregnancy and initiates a[nd] maintains the milk secretion after pregna[ncy]. FSH stimulates the growth of ovaries a[nd] testes at puberty and also stimulates them [to] produce the respective gametes. FSH a[nd] LH together stimulates the ovary to secr[ete] oestradiol. LH is also known as the *interst[itial] cell stimulating hormone* or ICSH. It he[lps] in the release of ovum from the ovary a[nd] stimulates the secretion of progesterone fr[om] the latter. LH or ICSH stimulates the te[stes] to produce testosterone in the male.

The *intermediate lobe* of the pitui[tary] produces only one protein hormone ca[lled] the *melanocyte stimulating hormone* (MS[H]) which makes the skin colour darker in lo[wer] vertebrates, like amphibia.

The *posterior pituitary* releases into [the] blood two peptide hormones, *oxytocin* [and] *vasopressin* (or *antidiuretic hormone* or AD[H]). These hormones are synthesised in [the] hypothalamus and are carried along ne[rve] fibres to the posterior pituitary which st[ores] them and secretes them in the blood. Oxyt[ocin] causes the contraction of the uterus in [the] female during child birth and also help[s] the expulsion of milk from the breast d[uring] sucking by the child. ADH increases

...rption in the distal convoluted tubules ...llecting tubules of the kidney and thus ...vent the excess loss of water in the ...(see chapter on Excretory system). ...ency of ADH secretion increases urine ...to a large extent (diabetes insipidus).

Integrated Role of Hormones on homoeostasis

...moeostasis is the constancy of the ...nal environment of the body. Hormones ...effective in maintaining growth and ...olution, body temperature, metabolism ...ucose, water and salt balances, etc. By ...r influences on various target organs, ...mones help to maintain the constancy of ...blood sugar level, body temperature, body ...er content, osmoconcentration of body ...ds, blood glucose level, heart rate and ...rial blood pressure. In other words, ...mones may help to maintain homoeostasis ...well coordinated actions.

To enable the maintenance of homoeostasis by hormones, their secretions are often under the *feedback control* by factors or other hormones produced by their effect in the body. For example, hypothalamus produces the thyrotropin releasing factor (*TRF*) which stimulates the anterior pituitary to secrete thyrotropin (TSH); the latter stimulates the thyroid to secrete thyroxine. *If* the level of thyroxine is more than normal in the blood, *a negative feedback* effect of the high blood thyroxine is exerted on the hypothalamus and pituitary so that they secrete less TRF and TSH respectively (Fig. 9.3). Similarly, a rise in the blood level of TSH also may depress effect TRF secretion from the hypothalamus by a negative feedback effect. These ultimately bring down the blood thyroxine level to normal because less thyroxine is produced now due to the fall in TRF and TSH secretions. On the other hand, a fall in the blood thyroxine level

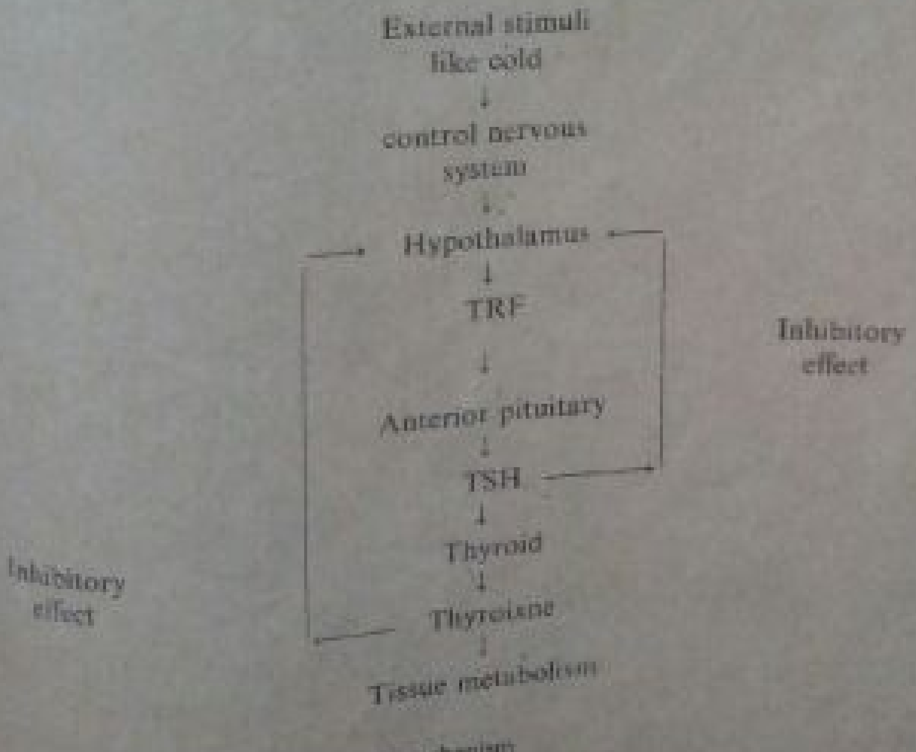


Fig. 9.3 A feedback control mechanism

below the normal removes the negative feedback effect of the latter on the hypothalamus and on the pituitary so that more TRF and TSH are secreted from them respectively, the thyroid is consequently stimulated to secrete more thyroxine and the blood thyroxine rises to normal again. Thus, homoeostasis is maintained with respect to thyroxine. There are many cases of such *feedback control of a stimulating (tropic) hormone by the hormone of the target endocrine gland.*

There are cases again where the secretion of a hormone is under the *feedback control by a metabolite*. For example, the output of insulin depends on the level of glucose in the blood. After a meal, the sudden release of glucose from the intestine into the blood raises the blood sugar level which stimulates insulin secretion; insulin then lowers the blood sugar level to normal again; on the contrary, a fall in the blood sugar level removes this stimulating effect and insulin secretion falls; thus the blood sugar is prevented from falling further. This helps in the maintenance of blood sugar homoeostasis by insulin.

Besides such feedback controls by other hormones and metabolites, secretions of some hormones are also controlled by nerves; for example, the secretion of epinephrine (adrenaline) by the adrenal medulla is under the control of the sympathetic nervous system which is also involved in maintaining homoeostasis in the body.

Pheromones

An entirely different category of chemical coordinators consists of *pheromones* which are chemical substances released in the *external environment* by the *exocrine glands*. The pheromone, secreted by a member of a particular species, is identified by other members of that species and serves, therefore, as a means of communication between them. For example, foraging worker ants secrete a pheromone along their paths to and from the nest and other ants of the colony can identify that path due to the pheromone and can use the same path.

TABLE 9.1

Sources, natures and principal functions of important hormones

Hormone	Source	Chemical nature	Functions
Thyrotropin releasing factor (TRF)	Hypothalamus	Peptide	Stimulates anterior pituitary to secrete TSH
Corticotropin-releasing factor (CRF)	—do—	—do—	Stimulates anterior pituitary to secrete ACTH
Somatostatin	—do—	—do—	Inhibits secretion of GH from anterior pituitary.
FSH releasing factor-LH releasing factor (LRF-FRF)	—do—	?	Stimulates secretions of FSH and LH from anterior pituitary
Prolactin releasing factor (PRF)	—do—	—do—	Stimulates secretions of FSH and LH from anterior pituitary.
Thyrotropin (TSH)	Anterior pituitary	Protein	Stimulates secretion of thyroxine from thyroid.
Adrenocorticotropic hormone (ACTH)	—do—	—do—	Stimulates adrenal cortex to secrete steroid hormones, particularly glucocorticoids
Growth hormone (GH)	—do—	—do—	Stimulates body growth

TABLE 9.1 (Continued)

...mone	Source	Chemical nature	Functions
...icle stimulating ...mone (FSH)	—do—	—do—	Stimulates gametogenesis in ovaries and testes, and with LH, stimulates estradiol secretion from ovary.
...inising hormone (LH) ...erstitial cell stimula... ...g hormone (ICSH)	—do—	—do—	Stimulates testosterone secretion from testes and progesterone secre- from ovaries; with FSH, stimulates oestradiol secretion from ovaries.
...lactin	—do—	—do—	Stimulates milk secretion from mammary glands.
...lanocyte stimulating ...mone	Intermediate lobe	—do—	Darkens amphibian skin
...ytocin	Produced in hypothalamus, released from posterior pituitary.	Peptide	Contracts uterine muscles and causes expulsion of milk from mammary glands
...tidiuretic hormone ...sopressin)	—do—	—do—	Reduces urinary loss of water.
...nephrine	Adrenal medulla	Amines	Increases rate and force of heart beats, blood glucose, heat production, O_2 consumption etc. Dilates bronchioles
...rtisol	Adreal cortex	Steroid	Increases gluconeogenesis from proteins, raises blood glucose level, has anti-insulin effects.
...dosterone	—do—	—do—	Increases sodium retention and potassium elimination
...yroxine	Thyroid	Iodinated amino acid	Increases cellular metabolism and energy production, helps in growth and differentiation
...rathormone (PTH)	Parathyroids	Protein	Increases blood calcium
...lcitonin (CT)	Thyroid & parathyroids	—do—	Lowers blood calcium
...sulin	Pancreatic β-cells	—do—	Lowers blood glucose and increases glucose utilisation
...lucagon	Pancreatic cells	—do—	Increases blood glucose and lowers liver glycogen
...elatonin	Pineal	Amine	Antigonadal; makes skin pale in amphibia
...enin	Kidney	Protein	Rise of blood pressure and secretion of aldosterone.
...stosterone	Testis	Steroid	Regulation of growth, development and functions of secondary male sex organs and characters.

TABLE 9.1 (continued)

Hormone	Source	Chemical nature	Functions
Oestradiol	Ovary	Steroid	Regulation of growth, develo- ment and function of seconda female sex organs and characte Control of menstrual cycle an pregnancy changes.
Progesterone	—do—	—do—	—do—
Relaxin	—do—	Protein	Softening of pelvic ligaments fo easy child birth.
Human chorionic gonadotropin (HCG)	Placenta	Protein	Stimulation of progesterone secre- tion from ovary during pregnanc
Thymosin	Thymus	Protein	Differentiation of lymphocytes in foetus and newborn infant.

EXERCISES

1. What are the chemical natures of hormones?
2. How is the calcium level controlled in the body?
3. Which hormones regulate the glucose levels in the body?
4. What is the function of the pineal gland?
5. Give the functions of the thyroid and the adrenal medulla.
6. How is the water and salt balance maintained in the body?
7. Describe the functions of the pituitary gland?
8. Is hypothalamus of any importance in the endocrine regulation? What are releasing hormones?
9. What is renin? Where is it produced and what is its function?
10. What do you understand by the feedback control of hormones?
11. What are gonadotropins and what is their role?

CHAPTER 10

Reproductive System

Most of the higher animals reproduce only sexually while some lower forms reproduce both asexually and sexually. In a number of sexually reproducing animals, males and females are separate. In order to understand the process of sexual reproduction, it is necessary to describe the structural differences between the male and female organs of reproduction.

Structural Differences Between the Female and the Male Reproductive Systems

THE FEMALE REPRODUCTIVE SYSTEM

As seen in Fig. 10.1, there is a pair of ovaries which produce the eggs and the female hormones. The ovaries are kept in position in the abdomen by mesenteries, called *mesovarium*. The eggs produced by the ovaries are shed into the abdomen (see Embryology on page 98) from where they enter the funnel-shaped fimbriated opening of the *Fallopian tube or oviduct*. The two oviducts open into the single uterus. The narrow terminal part of the uterus is the cervix. The uterus is followed by the *vagina* which opens to the outside through an opening which is completely separate from that of the urethra.

THE MALE REPRODUCTIVE SYSTEM

In males, the paired gonads are the *testes* (singular: testis) which, in most mammals, are accommodated in a pouch hanging in between the legs called the *scrotum* (Fig. 10.2). The testes produce numerous sperms at a time, unlike the ovaries which produce only *one* egg. The testes produce the male sex hormone, called *testosterone*. The sperms and testicular fluid are passed into the *rete testis* and then into the tubular region, the *epididymis*.

The sperms mature and become fully motile in the cauda epididymis or tail portion of the epididymis and are passed on to the *vas deferens*. The two *vasa deferentia* open

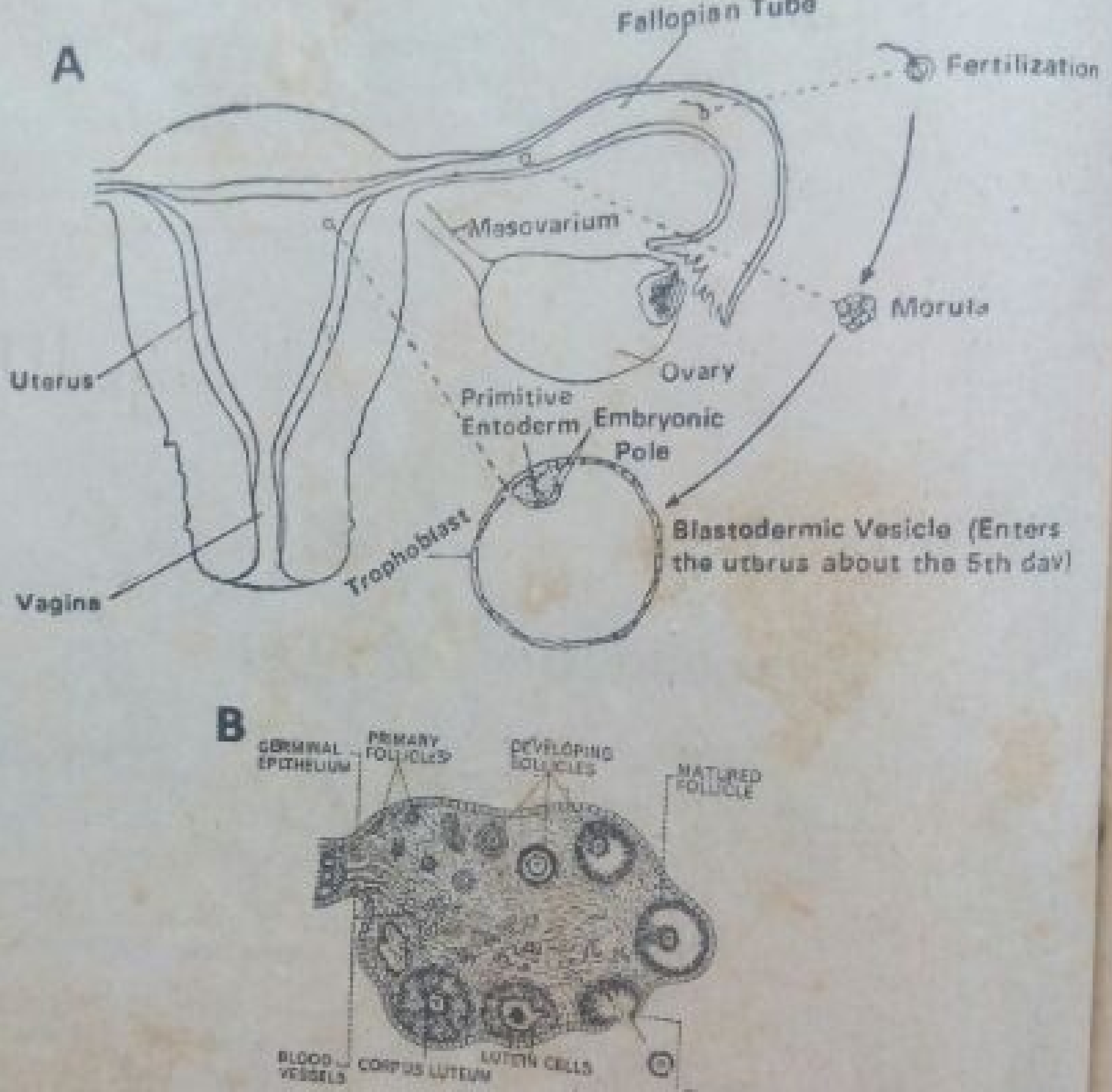


Fig. 10.1 (A) Female reproductive system (ovary and Fallopian tubes of one side are shown).
(B) Histology of the ovary (Transverse Section).

into the urethra, which also receives the secretions of the glands such as seminal vesicles, prostates, etc., as well as the urine via the ureters (see Chapter 5). Thus, in males, the excretory and reproductive organs have a single opening but, in females, they open separately. The urethra in males is continued into the external genital organ or *penis* and opens at its tip.

Histology of the Gonads

OVARIES

Each ovary is surrounded by the connective tissue; its interstitium is called the *stroma* and is composed of the connective tissue containing blood capillaries and nerves. The ovary consists of a number of germ cells, the oocytes, which are

...to form follicles. In the human female, ...umber of such follicles develop during ...ch cycle, called the *menstrual cycle* (Fig. ...), but only *one* reaches full maturity. The ...lly grown mature follicle is called the ...*afian follicle* (Fig. 10.1B), which has

Fig 10.2(A) Male Reproductive system

...ny layers of cells and the *ovum*. The ...mary ovarian follicle is at first a single ...l but under stimulation of FSH from the ...uitary gland (see Chapter 9), new cell ...ers are added which surround the ovum ...o form the Graafian follicle. The cells of ...e follicle synthesise the female hormone, ...*trogen*, when LH from the pituitary gland ...ts on the ovary. The ovum is released from ...e mature Graafian follicle by its rupture ...llowing the action of FSH and LH; this ...ocess is called *ovulation*. The follicular ...lls lining the ruptured Graafian follicle ...come enlarged and the follicle thus changes ...to the *corpus luteum* which also synthesises ...other hormone, namely, *progesterone*.

...tes

...ch testis is covered by the connective ...ue called the *tunica albuginea*. The testis ...made up of numerous *seminiferous tubules* ...which produce spermatozoa (Fig. 10.2B). ...ese tubules are highly coiled and packed ...und the connective tissue called the *interstitium* which has special cells, called the interstitial cells or *Leydig cells*. The Leydig cells produce the male hormone *testosterone* (Chapter 9). In a transverse section of the testis, the seminiferous tubules are seen to be made up of the outer germinal epithelium

Fig. 10.2(B) A transverse section of an adult testis.

(Fig. 10.2C). The different layers of the cells are the outermost *spermatogonia* and *sertoli cells*. The sertoli cells are large and their processes surround the different germ cells in the seminiferous epithelium. The spermatogonia divide and give rise to *spermatocytes* which in turn form the spermatids. The *spermatids* finally transform into the *spermatozoa* (Fig. 10.2D) which are released into the lumen (cavity) of seminiferous tubules and are then passed on to the epididymis. Spermatogenesis is a time-dependent process which cannot be accelerated by hormones.

The Ovarian Cycle

A woman's fertile life extends from the age of puberty at about 13 years to the

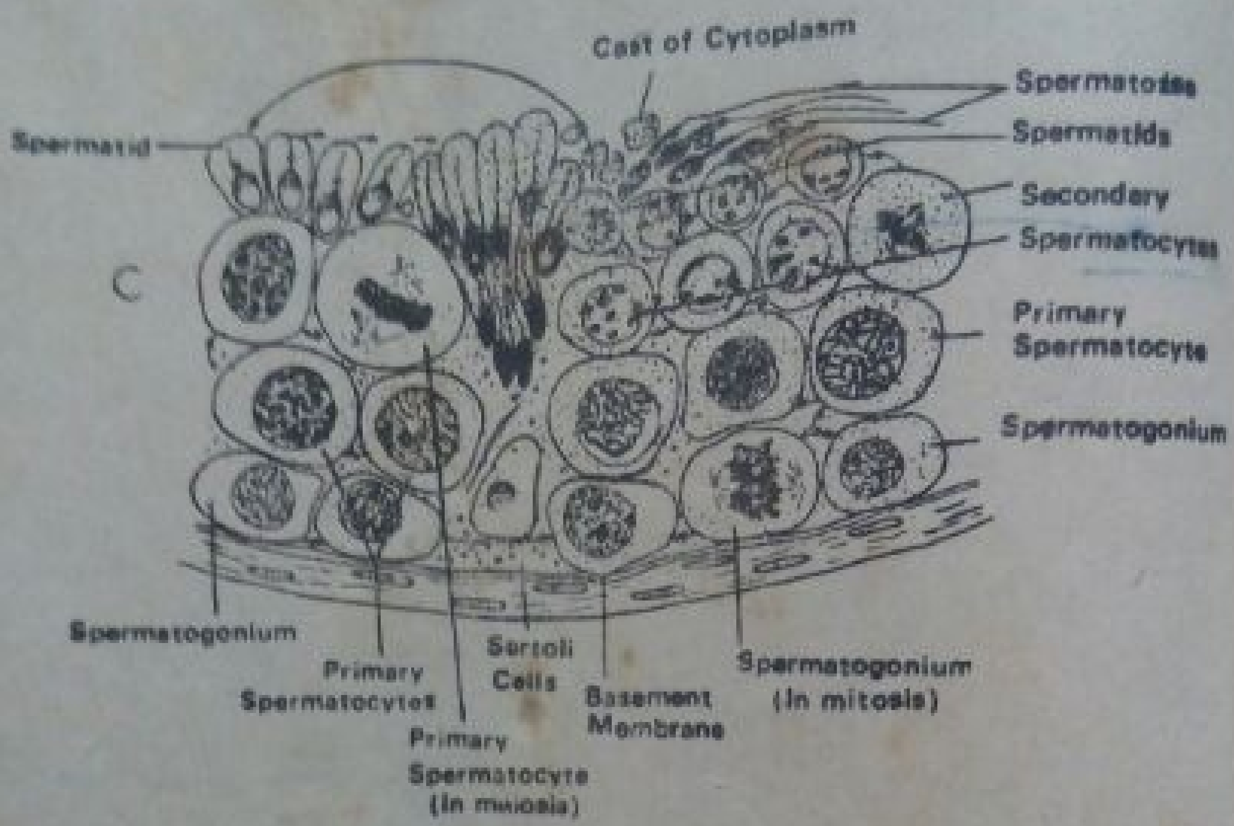


Fig.10.2 (C) A magnified view of the transverse section of the testis to show the stages of spermatogenesis. The arrow indicates the stages of development.

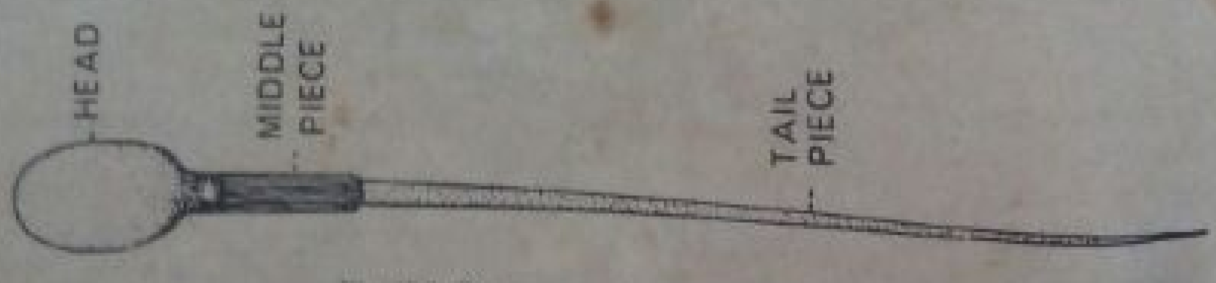


Fig. 10.2 (D) A mature human spermatozoa

menopause (arrest of the reproductive capacity) at about 45-50 years. After the menopause, the ovarian cycle stops and the woman is not able to bear children. In this span of reproductive life, the ovary goes through a cycle of change every month, about every 28 days. During each of these cycles, one mature ovum which is capable of fertilisation is released. The cycle is called the *menstrual cycle* and is characterised by *menstruation*, a process in which the blood, mucus and uterine tissues are eliminated.

The menstrual cycle is regulated by the action of oestrogen and progesterone on the uterine tissues (Fig. 10.3). Oestrogen stimulates the growth of the *myometrium* (uterine smooth muscle) and *endometrium* consisting of the uterine epithelium glands and connective tissues. Progesterone acts upon the oestrogen-primed endometrium to convert it into an actively secreting tissue. The glands become coiled and filled with secretion; the blood vessels become spirally coiled and numerous; various enzymes

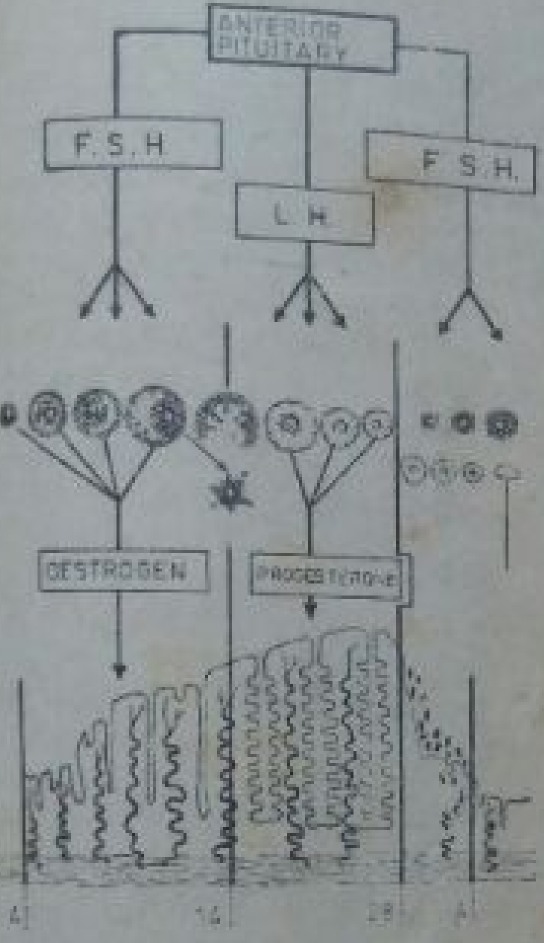


Fig. 10.3 Relationships of pituitary-ovary-endometrium during the menstrual cycle.

the glands and connective tissues. All these changes provide a favourable environment for implantation of the fertilised ovum.

The endometrial changes throughout the normal non-pregnant menstrual cycle are regulated by the action of oestrogen and progesterone (Fig. 10.3).

1. The fall in the levels of progesterone and oestrogen in the blood, following regression of the corpus luteum, deprives the highly developed endometrial lining of its hormonal support; this results in constriction of the uterine blood vessels, which leads to the diminished supply of oxygen and nutrients. The lining epithelium and the underlying connective tissue and blood vessels are sloughed off and *menstrual flow* begins, marking the first day of menstruation and the menstrual cycle.

2. After the initial period of vascular constriction, the endometrial arterioles dilate, resulting in haemorrhage through the weakened capillary walls; the menstrual flow consists of this blood mixed with the endometrial debris.

3. The *menstrual phase* continues for 3 to 5 days, when the levels of oestrogen in the blood are low.

4. The menstrual flow ceases as the endometrium begins to repair itself under the influence of the rising blood oestrogen concentration; this period, the *proliferative phase*, lasts for 10 days, between the cessation of menstruation and ovulation.

5. Following ovulation and formation of the corpus luteum, progesterone, acting along with oestrogen, induces the secretory phase in the endometrium between 15 and 27 days as described earlier.

6. The *secretory phase* is terminated by disintegration of the corpus luteum and the menstrual cycle is completed.

After the 28th day, the menstrual cycle is repeated. This cyclic rythm of changes in the reproductive system is not seen in males. In males, sperms are produced continuously after the onset of puberty. In females, under certain abnormal conditions, high levels of FSH and LH secrete at a very early age and stimulates to ovary to secrete hormones and release ova. Such an onset of menstruation at an age earlier than the normal (13 years) is called *precocious puberty*.

Fertilisation

During the process of mating or copulation, spermatozoa are introduced by the male into the vagina of the female. The spermatozoa migrate up the uterus up to the oviduct

or Fallopian tube, where one of them fuses with the egg and a *zygote* is formed (Fig. 10.1). This process is called fertilization. Fertilization can be *internal*, inside the body as described above, or *external*, as in the case of a frog where both the eggs and sperms are passed out into the medium of water where they fuse.

ARTIFICIAL INSEMINATION

Utilising the knowledge of the methods of fertilisation, it is now possible to make the females of many animals pregnant by artificially depositing the sperms in the vagina. This is called *artificial insemination*. In many farm animals, normal copulation or mating can be completely eliminated and replaced by artificial insemination. This involves the collection of the spermatic fluid from the males and storing it suitably for subsequent use. At any desired time, small quantities of the fluid can be taken and introduced into the vagina or the uterus of the female. This method of initiating pregnancy in farm animals has two advantages. The spermatic fluid from a good quality bull or stallion (male horse) may be used to inseminate a number of females. The preserved fluid may be sent to different places, thus avoiding the necessity of transporting the male animals for purposes of breeding. Artificial insemination is one of the well known and accepted methods for improving the quality of cattle and other farm animals. Artificial insemination may also be used for human beings under medical supervision.

Early Development

In mammals, the fertilised egg or zygote divides repeatedly to form a mass of cells which is transported into the uterus and is attached with its walls. This process is called *implantation* and establishes vascular contact between the uterine tissue of the mother and the growing embryo. A number of tiny finger-like projections arise from the outer covering of the embryo or foetus (the developing young of a mammal) and are embedded in the tissues of the uterus. Gradually, pools of blood form around these finger-like processes. It is through this vascular contact, the *placenta*, that the foetus derives its nourishment and oxygen, and eliminates excretory wastes. Human placenta also secretes in the maternal blood several hormones including oestradial, progesterone and human chorionic gonadotropin (see Chapter 9). The blood systems of the foetus and the mother are never continuous with each other. The thin membrane that seperates them allows the exchange of various substances by diffusion or active transport. The main blood vessles from the placenta enter the foetus through a thick cord called the *umbilical cord*. At birth, this cord is cut, after which the baby ceases to draw its nourishment through the placenta.

Fertility Control

In this world of growing population, India's population alone stands at 600 million and that of China at 900 million. The continuation of the growth of population at the present rate will lead to a *population explosion*. Not only is population control desired by many, but is necessary for the well-being of all societies.

Intra-uterine devices (IUD) placed in the uterus prevent the implantation of the fertilised ovum. Some operative procedures are also used, like *tubectomy* in females and *vasectomy* in males, which involves the removal of a small segment of the oviduct or vas deferens and the two cut-ends are tied separately with thread. Another important method is the use of hormone-containing pills or tablets which interfere with the process of ovulation. Research is being carried out in several Indian laboratories to find new approaches to the control of fertility in the male and femal

EXERCISES

What are the functions of the ovary and the testis?

Point out the difference in the male and female urethra.

Where does fertilisation occur in mammals? What is implantation?

What is the importance of the Leydig cells?

Explain briefly the female reproductive cycle. What is its importance? Is there any similar cycle in the male?

What is artificial insemination and what is its importance?

Describe the role of placenta.

Anatomy and Physiology: Plants

CHAPTER 11

Meristems

plant begins life as a single fertilized cell, which by numerous divisions gives se to a young embryo. In the early stages, ll division occurs throughout the embryo. ater, however, it becomes restricted to rtain parts of the plant body while the ther parts assume activities other than the owth. Thus, embryonic tissues persist roughout the life of the plant and are ponsible for growth in length and production of leaves, branches and flowers. These calised, perpetually young groups of cells, hich primarily lead to the formation of the ew cells, are called the *meristems* (Greek, *eristos*, meaning divisible). For example, if bean seed is opened, the plumule and dicle are seen embedc' 1 between the two yledons (Fig. 11.1). The: have at their ices groups of cells capable of dividing ntinuously; these are the meristematic ues.

The cells of the meristems exhibit certain ecial cytological characteristics. The meristematic cells are thin-walled, usually isodiametric and are richly protoplasmic. They possess relatively large nuclei, small or no vacuoles, small amount of endoplasmic reticulum and mitochondria and have a less elaborate internal structure. The cells have plastids at the proplastid stages and are metabolically highly active.

Types of Meristems

The meristems are classified on the basis of various criteria, such as their position and function.

The meristem located at the tip of a shoot is known as the *shoot apex* and the one at the tip of a radicle or a root is called the *root apex*. The shoot apex and the root apex are, therefore, referred to as the apical meristems (Fig. 11.1), which are of prime importance in the plant body. Another important group of meristems, which arise comparatively late in life of the plant or its organs,

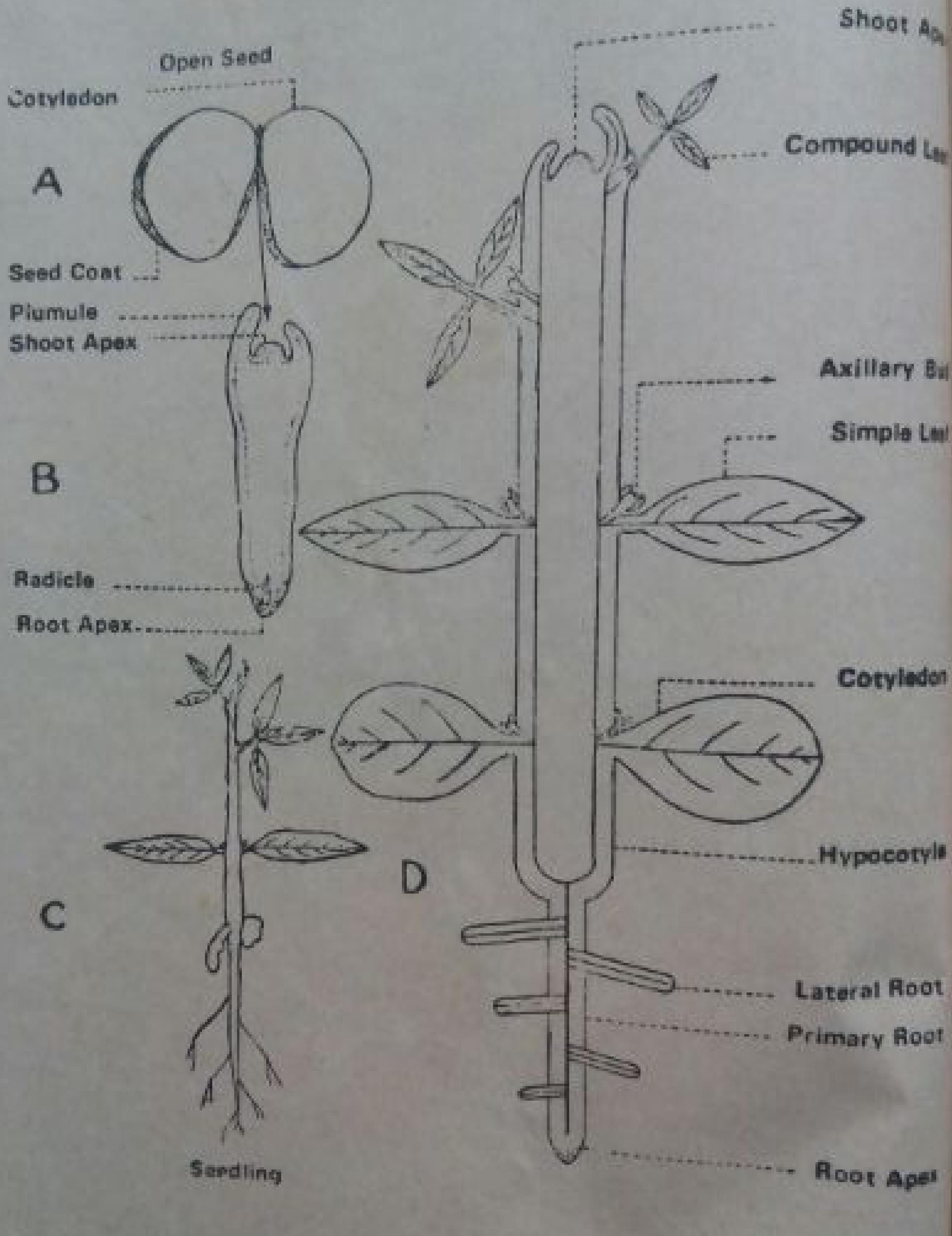


Fig. 11.1 Organisation of a seed and a seedling: (A) Cotyledons of a seed opened to show the embryonic axis; (B) Embryonic axis of the seed (enlarged); (C) A seedling; (D) Sectional view of a seedling

s known as the lateral meristems (vascular ambium and cork cambium). These meri-stems are involved in the increase in the iameter of a stem or root. More detailed escription of the lateral meristems follows n Chapters 13 and 15.

Structure and Organisation of Apical Meristems

EGETATIVE SHOOT APEX

Shoot apex is formed either at one end of e axis of the embryo or it may form the il of a leaf. The shoot apex is always overed by young leaves and can be seen nly after their removal. A good example to how the shoot apex easily is hydrilla Fig. 11.2).

The summit of the shoot apex is dome-haped (Fig. 11.3). Cell divisions from its anks at the base of the dome result in one or more of leaf primordia which retain their riginal size and shape. This process conti-ues throughout the vegetative phase.

In angiosperms, the organisation of the shoot apex is based on the planes of the cell division that occurs in the apex, resulting in two zones known as the *tunica* and the *corpus* (Fig. 11.4). This type of organisation was first observed by Schmidt in 1924. The tunica constitutes one (or sometimes more) peripheral layer in which, during the cell division, wall formation takes place at right

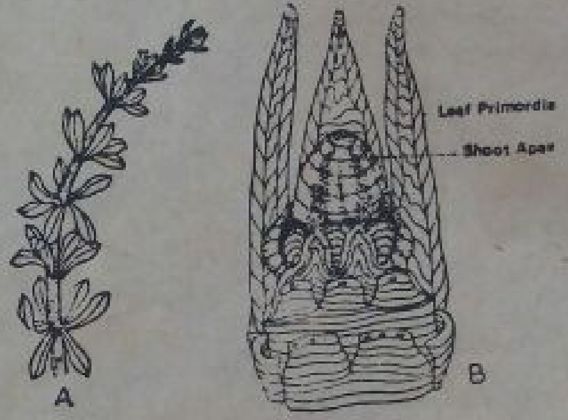


Fig. 11.2 Shoot apex of *Hydrilla:* (A) Shoot of *Hydrilla*; (B) Enlarged view.

Fig. 11.3 A longitudinal section of the shoot apex.

angles to the surface of the apex, i.e., anticlinally and results in the surface growth. On the other hand, the corpus is a group of cells overarched by the tunica and exhibits mitosis in all directions, resulting in the increase in volume. If there is more than one tunica layer, the outer layer contributes to the epidermis while the other layers, by a change in the planes of divisions, participate in the formation of the leaf primordia and cortical tissues. The corpus is responsible for the production of the cortex and vascular tissues.

Based on the rate of the cell division, two regions can be recognised in the shoot apices (Fig. 11.5). The summit region exhibits relatively few mitotic divisions, whereas at the flanks of the apex the rate of division is high from where the leaf primordia are due to arise. The summit becomes more active at the time of flowering. Just below the summit, the cells towards the surface and the centre, i.e., the future cortex and pith, respectively, mature early while the cells in between them remain meristematic, divide longitudinally and produce the procambium. The procambium gives rise to the vascular bundles.

REPRODUCTIVE APEX

During the reproductive phase, some or all of the vegetative apices are converted into reproductive apices. At the phase of floral initiation, the apex stops producing the leaf primordia. The summit of the apex which was hitherto inactive during the vegetative phase starts dividing actively. The apical meristem exhibits a change in shape and increases in size, irrespective of whether it forms a flower or an inflorescence. In *Rosa*, for example (Fig. 11.6), at the time of flowering, the cells at the flanks of the apex are depleted in producing sepals and petals,

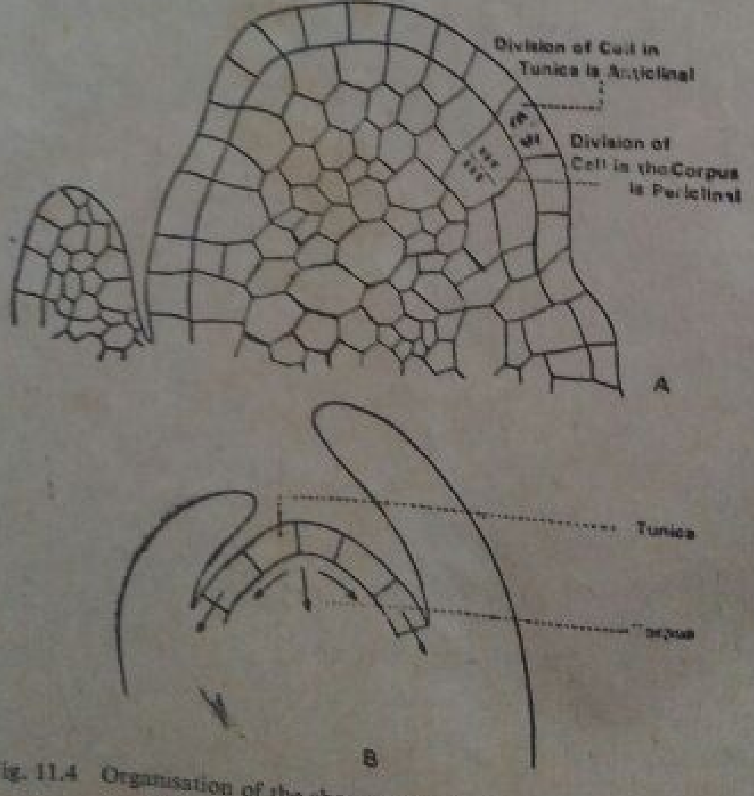


Fig. 11.4 Organisation of the shoot apex into the tunica and corpus
(A) Semidiagramatic; (B) Diagram...

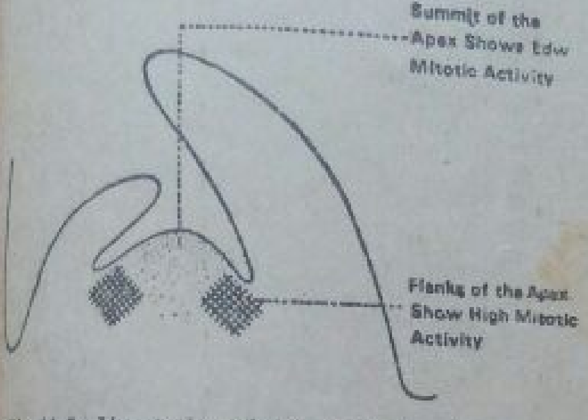


Fig. 11.5 Vegetative shoot apex to show the regions of activity.

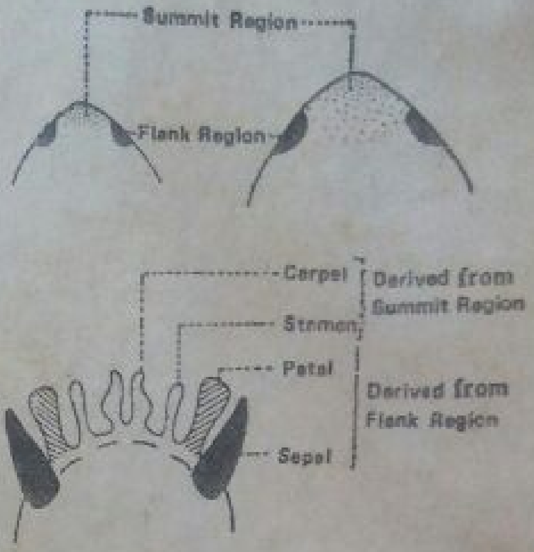


Fig. 11.6 Transformation of the shoot apex from the vegetative to the reproductive phase in *Rosa*.

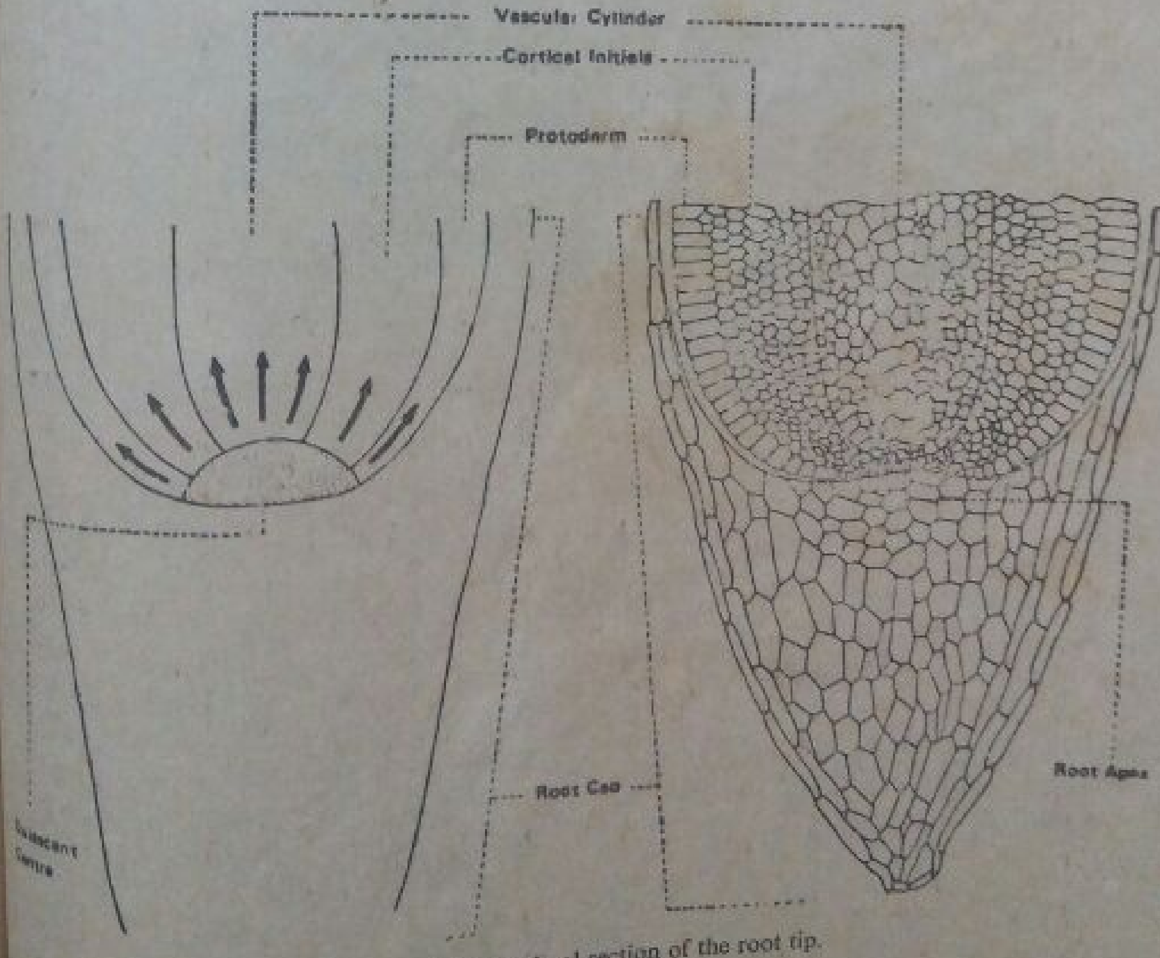


Fig. 11.7 A longitudinal section of the root tip.

while the cells in the summit participate in the formation of stamens and carpels.

ROOT APEX

The root apex is differentiated from the other end of the embryonic axis (see Fig.11.1). In contrast to the shoot apex which is truly apical, the root apex is subterminal because it is covered by the root cap. The root cap protects the meristem and also assists in the penetration of the root into the soil. The root apex also differs from the stem apex in not having lateral appendages, such as the leaf primordia. There are many ways in which the inner structure of the root a may be organised. Histologically, root api exhibit precise meristematic regions of futı epidermis (protoderm), cortex (cortical i tials) and vascular cylinder (Fig. 11.7). group of initials situated at the apex produ cells towards the axis which form the ep dermis, cortex and the vascular cylinder a well as cells in an opposite direction t produce the root cap. Clowes, a Britis plant anatomist, showed that a few cell occupying the central part of the dista region of the root apex show very low mito- tic activity and is called the *quiescent centre*.

EXERCISES

1. What are meristems? What is their role in plants?
2. Name the different types of meristems occurring in the plant body.
3. Describe the organisation and regions of activity in the shoot apex.
4. What are the changes that occur in the apex at the time of flowering?
5. What is the quiescent centre? Where is it located?
6. Distinguish between the shoot apex and the root apex anatomically.

CHAPTER 12

Water Relations of the Plant Cell

TER not only enters a plant through the of the root but also moves to other s through cells and tissues. It is, there-, important to study the principles ich regulate water relations of the plant ls.

It is common knowledge that life cannot st without water. The importance of water be realised from the fact that it constis about 90 per cent of the total weight a cell in a leaf or a petal. Water is a solvent which several substances are dissolved d it participates as a reagent in many tions such as those of photosynthesis. er also serves as the medium for the sport of inorganic salts and food materi- the vascular system. Water helps in germination of seeds and provides idity to growing cells and, thus main- their form and structure.

The cytoplasm in a plant cell is enclosed in the cell wall. The plasmalemma lies just underneath the wall. Mature plant cells generally contain a large central vacuole (Fig. 12.1B). The cell wall is generally permeable (allowing free mobility) to the solvent and solutes of the external solution. The plasmalemma, alone or together with the cytoplasmic film and the vacuolar membrane (tonoplast), constitutes the selectively permeable membrane. This membrane allows certain molecules to enter and prevents others. Water molecules move freely across such a membrane.

This special type of diffusion of water across a selectively permeable membrane from an area where it is in lower concentration is referred to as *Osmosis*. Let us examine the process of osmosis in a physical system. Osmosis is a function of three factors: temperature, pressure, and the number of

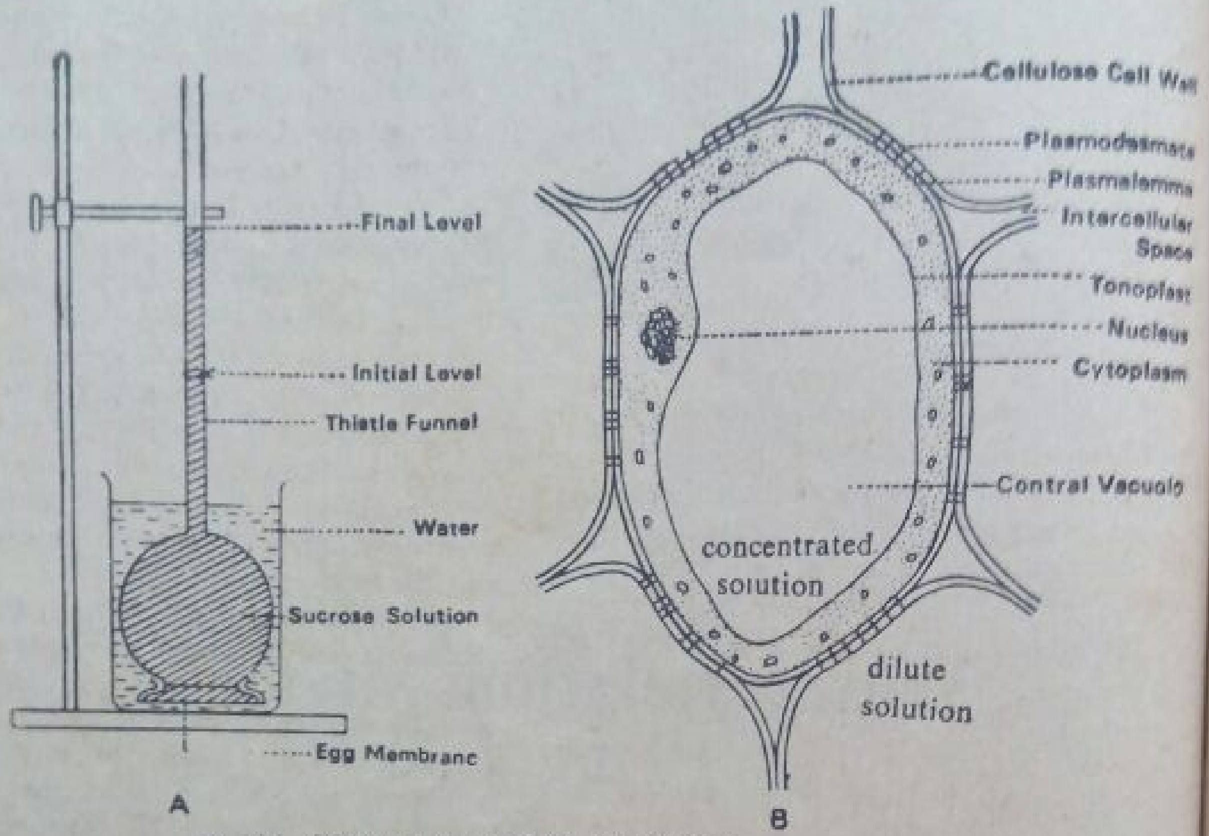


Fig. 12.1 (A) Demonstration of osmosis; (B) Cell as an osmotic system.

solute molecules in the solutions on the two sides of the selectively permeable membrane e.g. egg membrane, sheep bladder etc.

When the membrane separates pure water on the two sides, each being at different temperature, the molecules of water will move from the side at higher temperature to that of lower temperature, provided the pressure is the same on the two sides.

When water on the two sides has the same temperature but is subjected to different pressures, water molecules will diffuse from the high pressure side to the low pressure side.

In the third situation, if pure water is separated by a selectively permeable membrane from a solution of a given strength (say, 0.5 M sucrose), the net movement of water molecules takes place from pure water (side) to the solution (side) (Fig. 12.1A). Here, water is moving from its region of higher concentration (pure water has more water molecules than a solution) to its region of lower concentration. The solute would have moved in the opposite direction (that is, from the solution to pure water) but the selectively permeable membrane either does not permit its movement in that direction or it allows the movement only very slowly.

If water is replaced by a dilute solution with reference to the given sucrose solution, water will still move in the direction of the solution with a higher concentration of sucrose.

The net movement of water into the cell due to osmosis results in the development of a hydrostatic pressure known as the *osmotic pressure*. When the hydrostatic pressure is equal to the pressure developed due to osmosis, then this pressure will be at the equilibrium stage.

Osmotic pressure in a physical system is measured as the minimum force required to

prevent the osmotic entry of water into a system.

It is evident that the direction of the osmotic movement of water and the resultant osmotic pressure would depend upon the temperature, pressure and difference in the number of solvent and solute molecules on the two sides of a selectively permeable membrane.

The increase in temperature or pressure *increases* the kinetic energy of the solvent. However, the presence of a solute lowers the kinetic energy because the attraction between the solute and the solvent molecule lowers the molecular motion. The increase in temperature or pressure increases the free energy (energy available to do work), while the increasing concentration of the solutes lowers it. In each of the three instances, water, thus moves from a region of higher free energy to that of lower free energy.

In modern terminology, the osmotic pressure is equivalent to the osmotic potential in concept but opposite in sign, i.e., $\pi = -OP$, where π is the osmotic potential and OP the osmotic pressure. π can be expressed in energy terms, whereas OP can be expressed only in terms of atmospheres. OP always has a positive value, since it increases gradually from zero as the solute concentration increases, while π is characterised by a negative value since π for pure water is taken as zero by convention and gets lowered with the increase in the number of solute molecules.

If a plant cell is put in a medium of pure water or solution of lower solute concentration than the sap inside, water enters the cell (if the cell is not already fully turgid) as a result of osmosis. Such an entry of water results in a hydrostatic pressure called the *turgor pressure* (TP) which presses on the cell wall. But since forces occur in pairs (Newton's third law) of equal magnitude but in the opposite direction, the turgor pressure is balanced by an equal pressure exerted by the cell wall, called the wall pressure (WP). With the continued entry of water into the cell, the magnitude of WP keeps on increasing until the cell becomes fully turgid. Before the cell reaches full turgidity, it may be said that there is a water deficit or diffusion pressure deficit (DPD). At full turgidity, therefore, DPD=0 and WP or TP is equal in magnitude to the osmotic pressure of the solution outside, i.e., WP=OP .The pressure of the wall at full turgidity prevents the osmotic entry of water. In a non-turgid cell, therefore, DPD=OP−WP. DPD in modern terminology is referred to as the *water potential* (ψ). In its physical value, $\psi = -DPD$. The water potential is a term related to the chemical potential and free energy of water. The value of the water potential of pure water at normal temperature and pressure is zero. This is the highest value of ψ which is lowered by the increase in the solute concentration, while DPD has positive values only. The value of the water potential is, thus, given by $\psi = \pi + WP$.

The value of DPD or ψ determines the direction and rate of water movement between two systems (two adjacent cells or a cell in an open bathing medium), while the rate depends upon the magnitude of the difference in the potential (ψ) or the pressure (DPD). The direction is always from the lower DPD to the higher DPD or from the higher ψ (maximum zero) to the lower ψ (increasing numerical value with the negative sign).

If a cell is placed in a solution of higher solute concentration than that inside its vacuole (hypertonic), water moves out of the cell. This flow is called *exosmosis*, while the reverse flow of water (caused by a cell being put in a solution of lower solute concentration) is known as *endosmosis*. If no net movement of water takes place, the outside medium is considered as isotonic to the cell sap.

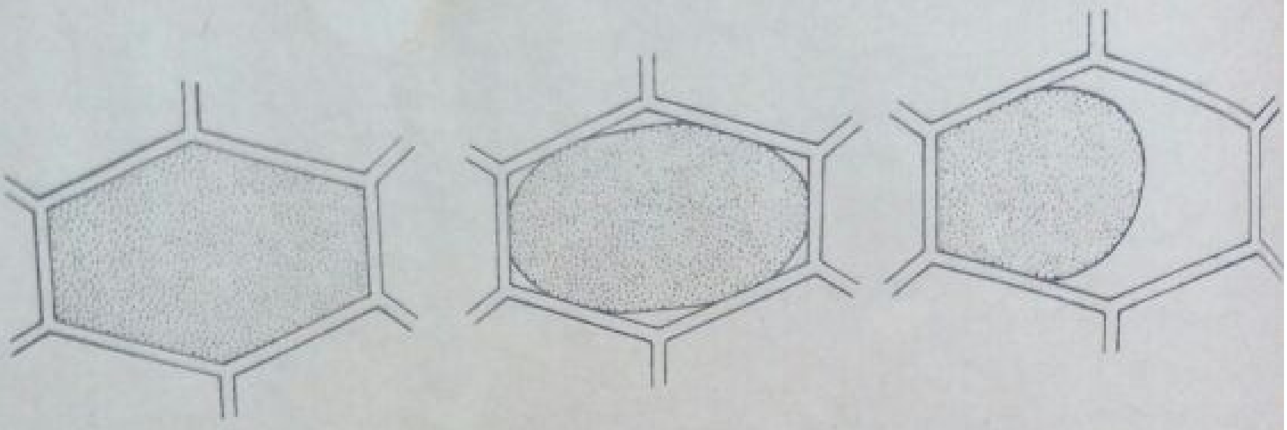


Fig. 12.2 Conditions of protoplast: A protoplast in a turgid cell; B protoplast at incipient plasmolysis; C Protoplast at plasmolysis.

If a plant cell is put in a hypertonic solution, water starts moving out of it, causing shrinkage in the cell volume. When the cell volume becomes minimum (at TP=0), the plasmalemma starts losing contact with the wall and eventually rounds up in the cell. A cell in this condition is said to be plasmolysed and this process is known as *plasmolysis* (Fig. 12.2 A-C). The stage when plasmolysis just begins and the plasmalemma starts receding from the wall is known as *incipient plasmolysis*. When a cell in this condition is transferred to pure water, it is observed that water moves into the cell and turgidity is regained. This process is termed as *deplasmolysis*. Plasmolysis and deplasmolysis can be demonstrated in a living cell. A good material for this study is the lower epidermis of the leaf of *Rhoeo discolor* in which the vacuole is filled with a coloured sap.

The osmotic entry of water into the cell acts as a driving force for the cell's expansion and elongation. A flaccid (non-turgid) cell is incapable of elongation. The turgidity and flaccidity of the guard cells are also important in regulating the opening and closing of stomata. The driving force, again, is the water movement in and outside the cells.

EXERCISES

1. Describe the plant cell as an osmotic system.
2. Discuss the water flow across a semipermeable membrane in a physical system at varying T (constant P), varying P (constant T), and the varying number of molecules of a solute at (constant T and P).
3. Explain how in a living cell ψ is something more than π. What is the relationship between the two parameters?
4. Describe how DPD or ψ determines the direction of the water flow in plant cells.
5. If a cell with OP=6 and TP=5 is surrounded by the cells, all with OP=3 and TP=1, what will be the direction of the water movement?
6. Explain the terms plasmolysis and deplasmolysis, using suitable examples.
7. State how osmosis is related to the cell growth and turgor movements.

CHAPTER 13

Root—Structure and Functions

THE root is the underground part of a plant axis. All the roots of a plant constitute the root system. In dicotyledonous plants, the root system consists of a tap root and its branches, whereas in monocotyledons it consists of stem-borne adventitious roots. The structure of the tissues and the anatomical organisation of the root bear close relationship with its functions like the absorption of water and solutes, long distance conduction of water and solutes, anchorage in the soil and storage of materials.

Primary Structure of the Roots

DICOTYLEDONOUS ROOTS (Bean is used as an example)

A transverse section of a young dicotyledonous root shows three regions, namely, the epidermis, cortex and vascular cylinder (Fig. 13.1A).

Epidermis

The epidermis is the outermost tissue of the root. It is typically uniseriate (single layered) and consists of closely packed thin-walled flat cells. There is no cuticle on the epidermis. Some cells of the epidermis show tubular outgrowths known as the root hairs.

Cortex

The cortex is uniform and simple. It consists of several layers of thin-walled parenchyma cells with conspicuous intercellular spaces. The cells contain storage materials like starch. The innermost layer of the cortex is known as the endodermis (Fig. 13.1B) and is well developed. It is structurally and physiologically different from the cells on either side of it. The radial and transverse walls of the endodermal cells contain a band of lignin and suberin, known as the *Casparian strip* and considered to control the movement of materials in the root. Later in the development of the root, all cells of the endodermis become thick-walled, except at positions opposite the protoxylem. These thin-walled cells are known as *passage cells*.

Fig. 13.1(A) A transverse section of a dicotyledonous root.

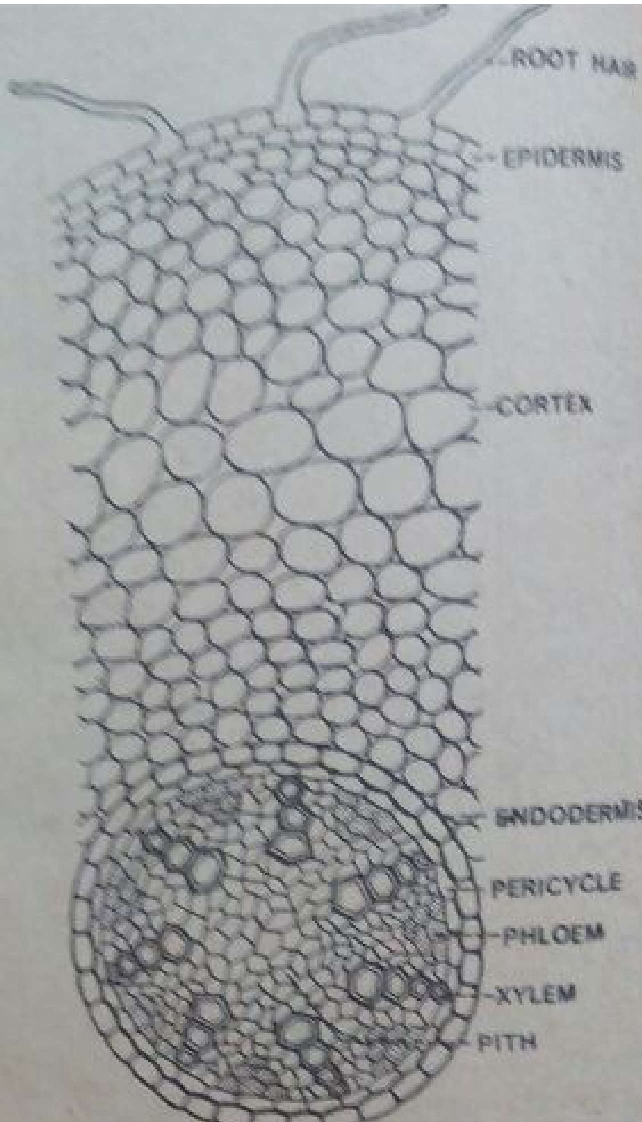


Fig. 13.1(B) A transverse section of a monocotyledonous root.

Vascular Cylinder

The central part of the root is occupied by the vascular cylinder which is more clearly demarcated in the root than in the stems. This structural feature is related to the differences in their functions. Beneath the endodermis and surrounding the vascular tissues is a layer of parenchyma cells known as the *pericycle*, which is involved in the formation of lateral roots and secondary growth. The vascular tissues, the *xylem* and the *phloem*, are arranged alternately in separate radial groups. The xylem extends along the radii into the centre of the root. In the root, the first formed xylem, known as the *protoxylem*, is towards the periphery of the vascular cylinder and the later formed xylem, known as the *metaxylem*, is located towards the centre. Such an arrangement is known as exarch condition. Based on the number of xylem arch, the roots are known as the *monarch*, *diarch*, *triarch*, *tetrarch*, and so on (Fig. 13.2). The root of the bean plant possesses a tetrarch condition, while that in the sunflower plant is triarch. In the dicotyledonous plants, the xylem plates usually extend into the centre to form a solid central core without any pith.

MONOCOTYLEDONOUS ROOTS (Maize is used as an example)

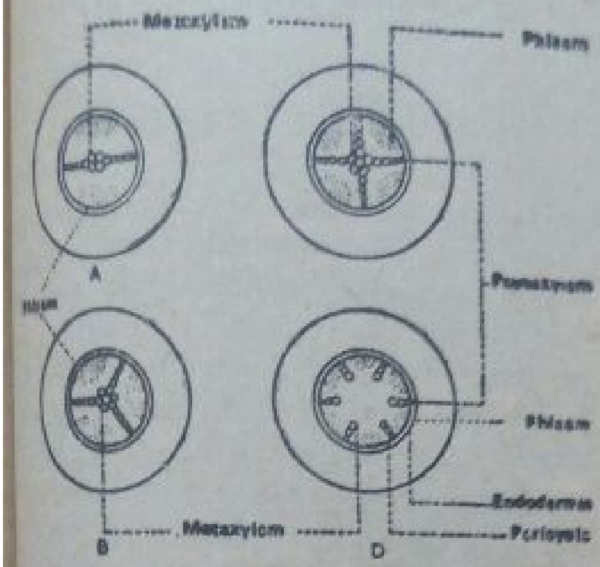


Fig. 13.2 Number and arrangement of the xylem archs in the roots (transverse section); (A) diarch; (B) triarch; (C) tetrarch; (D) polyarch.

A transverse section of a monocotyledonous root also shows three regions, the epidermis, cortex and vascular cylinder (Fig. 13.1B).

Epidermis

The epidermis is the outermost tissue with uniseriate thin-walled cells. Root hairs are present.

Cortex

The cortex consists of several layers of parenchymatous cells with intercellular spaces. The cortex is smaller than in the dicotyledonous root. The endodermis is characterised by the presence of Casparian strip.

Vascular Cylinder

The vascular cylinder is clearly delimited from the cortex. The vascular tissues are surrounded by a single-layered pericycle. In monocotyledons which usually lack secondary growth, the pericycle is involved only in the lateral root formation. Xylem and phloem are separate, alternate and are arranged radially. The xylem is exarch and polyarch. The xylem strands do not extend into the centre but the centre is occupied by a parenchymatous pith. The principal differences between the monocotyledonous and dicotyledonous roots are as follows:

Dicot root	Monocot root
The number of xylem strands is limited	The number of xylem strands is large
Pith is small or even absent	Pith is large
Secondary growth is present	Secondary growth is usually absent

The Root as an Absorbing System

One of the chief functions of the root system is the absorption of water and minerals.

ABSORPTION OF WATER

The absorption of water by the roots from the soil takes place mainly in the root hairs but also in the cells which lack root hair (Figs. 13.3 and 13.4).

Root hairs increase the absorptive area of the root. In the soil, the root hairs are in contact with the films of water surrounding the soil particles. Water present in the soil has a higher chemical potential than the cell sap of the root hairs because of the presence of various substances in the cell sap. This difference causes water to enter into the root hairs whose water potential becomes greater than that of the inner adjacent cells (Fig. 13.4). Hence, water moves into the adjacent cells whose water potential becomes higher than its inner neighbouring cells. Thus, a gradient of water potential is created in the cortex, including the pericycle which is in contact with dead conducting elements of the xylem. The xylem sap has low water potential, as a result of which water moves from the cortical cells into the tracheal elements. Water from the xylem is removed by transpiration in the leaf and this results in the lowering of water potential

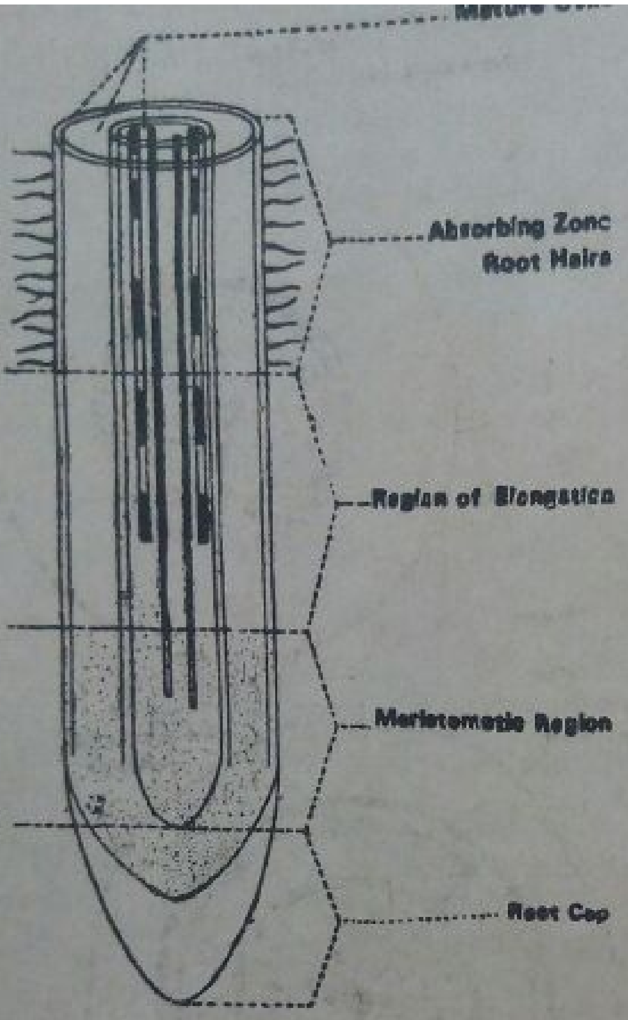


Fig. 13.3 A root tip, showing the absorbing zone of the root hairs.

in the xylem of the root and consequent absorption of water from the soil.

ABSORPTION OF MINERALS

The cells of the root absorb dissolved mineral salts in two ways. If the concentration of mineral substances is higher in the soil than inside the root cells, the mineral ions move into the cells of the root by diffusion, based on the concentration gradient, without utilising the metabolic energy of the cells. This process is known as the *passive absorption* and continues until an equilibrium is reached between the outside and inside of the cells. The absorption of mineral substances utilising the metabolic energy is known as the *active absorption* and explains the greater accumulation of mineral

SECONDARY GROWTH IN THE ROOTS

The tap root and main lateral roots of most of the dicotyledons show secondary growth, while the young roots do not. Secondary growth results in an increase in the girth of a root. Unlike in the dicotyledons, the roots of most monocotyledons do not undergo secondary growth. Secondary growth in a dicotyledonous root is described below.

Secondary growth begins with the appearance of the vascular cambium on the inner edges of the primary phloem strands (Fig. 13.5). The vascular cambium forms the

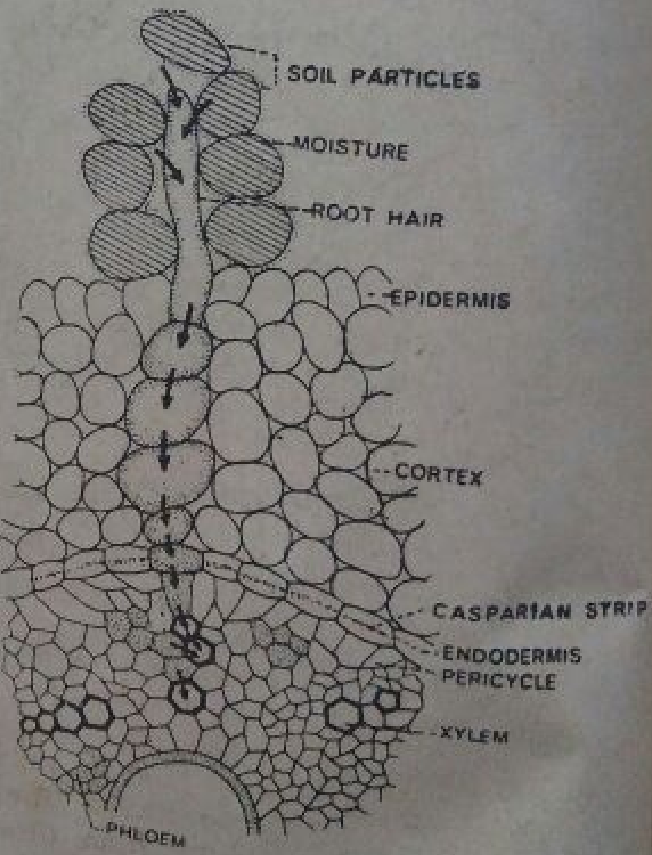


Fig. 13.4 Part of the transverse section of a root, showing the movement of water from the soil to the trachеary elements of the xylem. Arrows indicate the direction of movement through the selected sequence of the cells.

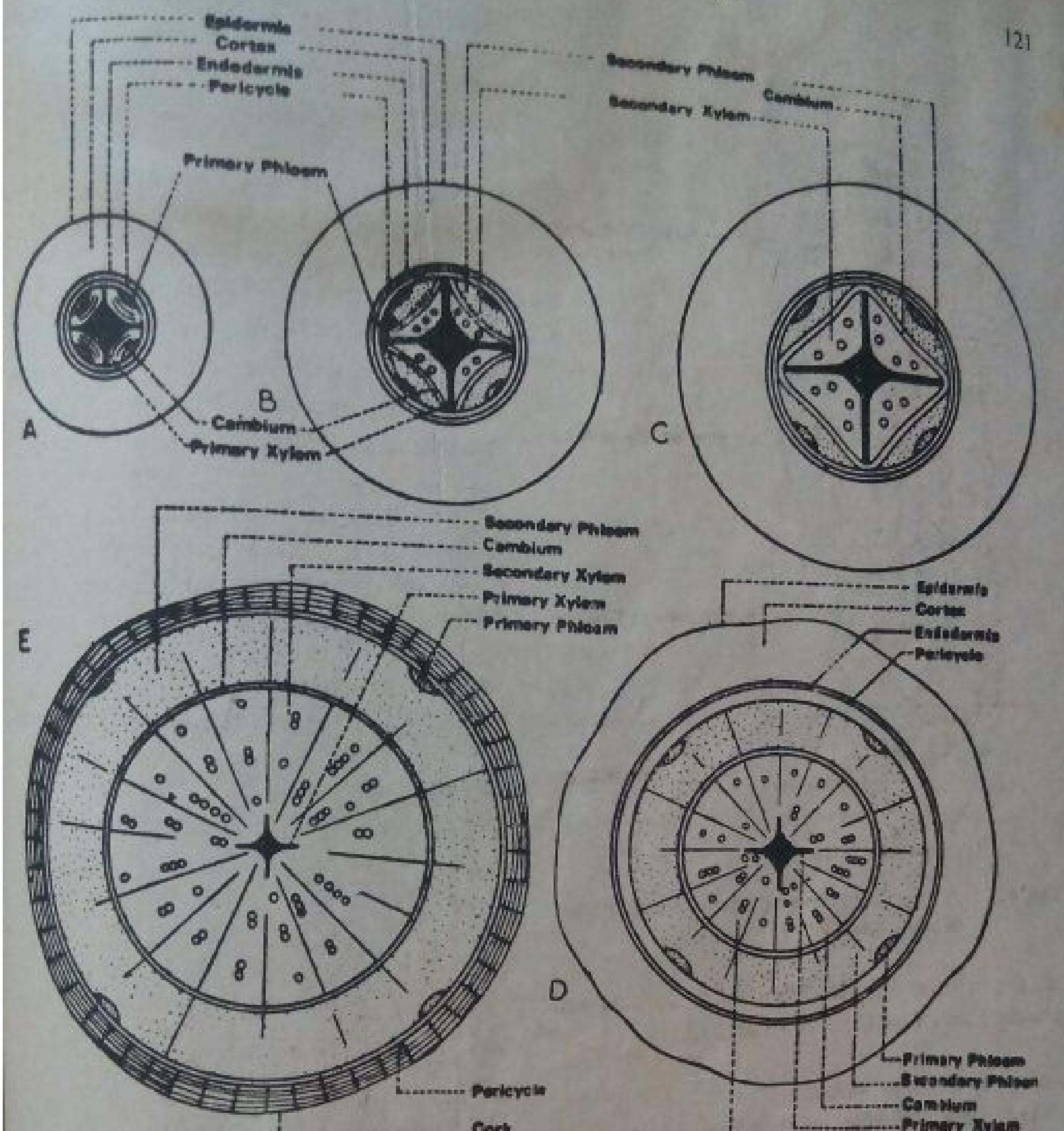


Fig. 13.5 Diagrammatic representation of the development of secondary tissues in a dicotyledonous roots. A, B, C, D, E represent different stages of the secondary growth.

secondary phloem and xylem. The pericyclic cells outside the primary xylem strand divide and the inner cells resulting from these divisions differentiate into the vascular cambium. These strips of cambium are joined laterally to the cambium located on the inner faces of the phloem and form a continuous cylinder. The cylinder of the vascular cambium appears in an undulating form in the transverse section of the root. The formation of the xylem from the cambium situated in the inner edges of the primary phloem precedes that from the cambium outside the primary xylem strands. As a result the vascular cambium soon becomes circular in outline. The circular vascular

cambium produces the secondary phloem towards the outside and the secondary xylem towards the inside. Details of the secondary vascular tissues are described in Chapter 15. The primary phloem is usually pushed towards the periphery by the presence of the secondary tissues produced inside and the primary xylem is pushed towards the centre of the axis.

The dividing cells of the pericycle outside the xylem strands, that are not involved in the production of the vascular cambium extend the divisions in the cortical region along the circumference of the root. The derivatives of these cells differentiate into the *cork cambium* (phellogen) which gives rise to the *cork* (phellem) towards the outside and the *phelloderm* towards the inside; the three together form the *periderm* of the root. The tissues outside the developing cork are generally sloughed off.

EXERCISES

1. Describe the internal structure of a dicotyledonous root.
2. What is endodermis? What is its structure and function?
3. Describe the internal structure of a monocotyledonous root.
4. What are the principal differences between a dicotyledonous root and a monocotyledonous root?
5. Describe the process of absorption of water in the roots.
6. Describe the process of secondary growth in the dicotyledonous roots.

CHAPTER 14

The Inorganic Nutrition of Plants

mineral elements that are essential in the of a plant, with the exception of carbon d oxygen, are obtained through the root em from the soil. Carbon and oxygen are ed from the air. The utilisation of vari- absorbed ions by a plant for growth and elopment is called the *mineral nutrition* of plant. Scientific approach to the role of mineral elements started with Sachs and p in 1850. Using the water culture tech- e, they demonstrated that carbon, hydro- oxygen, nitrogen, sulphur, phosphorus ium, calcium, magnesium and iron are tial for the healthy growth and develop- of plants. These elements are referred the *macronutrients* or *major elements* e of the relatively large quantities in h they are needed for plant life. Except which is required in small quantities, all the other elements are absorbed in considerable quantities. Plants also require some elements in minute or trace quantities which are called the *micronutrients* or *trace elements*. Some important micronutrients are manganese, zinc, boron, copper and molybdenum. Arnon and Stout (1939) gave the following criteria of essentiality for mineral elements: (i) the life cycle of a plant is incomplete without the particular element, (ii) the element cannot be replaced by another element, (iii) it is directly involved in the nutrition of a plant. The techniques that are generally used in the study of plant mineral nutrition are ash analysis and water and sand cultures. Figure 15.1 shows the effects of the deficiency of various mineral nutrients in barley plants grown in water culture.

Macronutrients

CARBON, HYDROGEN AND OXYGEN

These are not minerals in origin but are important structural constituents of a plant. These elements comprise the major portion of the dry weight of plants. Carbon is absorbed as carbon dioxide from the air. Hydrogen is released from water during photosynthesis. Oxygen is absorbed in the molecular form from the air and it is also generated within the plant during photosynthesis.

NITROGEN

Nitrogen enters into the structure of protein molecule and is, thus, an important component of protoplasm. It is also present in the impoitant compounds like amides, alkaloids, purines, pyrimidines, porphy[...] and enzymes. Nitrogen containing co[...] pounds play a major role in protein synth[...] The genetic material, DNA, contains [...] nitrogenous bases, purines and pyrimidin[...]

The common symptom of nitrogen de[...]ciency is *chlorosis*, that is yellowing [...] leaves due to the low content of chloroph[...] The symptom appears first in mature leav[...] and lastly in the young leaves. The nitroge[...] deficient plants develop purplish colorati[...] due to the synthesis of pigments other th[...] chlorophyll, like anthocyanin.

The excess of nitrogen supply to the pla[...] produces abundant leaves which are dar[...] green in colour. Excessive nitrogen reduc[...] the root system and delays flowering an[...] seed formation.

Fig. 14.1 The effects of the deficiency of various mineral nutrients in barley plants grown in water culture.

...HUR

...lphur is incorporated into protein as a ...tuent of three sulphur-containing ami... acids, cystine, cysteine and methionine. It ...so present in coenzyme A and in the ...mins, thiamine and biotin. Sulphur ...ases the root development. It also ...ases the nodule formation in legumes.

...he deficiency of sulphur also results in ...osis but, unlike nitrogen-deficient plants, ...yellowing first appears in the young ...es. In some cases, all the leaves show ...rosis at the same time.

...SPHORUS

...t is an important element which is in...ed in the energy transfer concerned with ...tosynthesis and respiration. It is present ...a constituent of ATP (adenosine triphos...ate), nucleic acids, the coenzymes NAD ...cotinamide adenine dinucleotide) and ...ADP (nicotinamide adenine dinucleotide ...sphate). The functions of these impor...t molecules have been detailed elsewhere. ...osphorus is present in high concentration ...cially in seeds in the form of phytic acid.

The deficiency of phosphorus causes ...nted growth and results in the development ...f purple anthocyanin pigments. Leaves ...come dark-greyish green and there is often ...mature leaf fall. Dead necrotic areas ...pear on the leaves, petioles and fruits. ...eficiency symptoms first appear in the ...der leaves. Anatomically, the vascular ...ues are poorly developed with the increa...d area of the pith tissue.

...TASSIUM

Potassium differs from all other macro...trients in not being a constituent of any ...etabolically important compound. Yet, ...ants require this element in considerable ...antities. It is involved in many of the ...ysiological processes like respiration, pho...synthesis, chlorophyll and protein synthesis ...d stomatal movements. Its role is not clear. It is required in large quantities for the synthesis of protein. Potassium is also considered to be involved in the hydration and permeability of cells and may act as a coenzyme or activator for many enzymes.

The deficiency of potassium produces stunted growth in plants. In several cases, its deficiency produces mottled chlorosis, necrotic shrivelling of the margins of the older leaves and sometimes *at the tip of* the leaf also (Fig. 14.2). The deficiency symptoms first appear in the mature leaves. Its deficiency in plants produces a decrease in the apical dominance due to the injury caused to the apex resulting in a bushy habit. In some cereals, this potassium deficiency leads to the development of weak stalks and increase

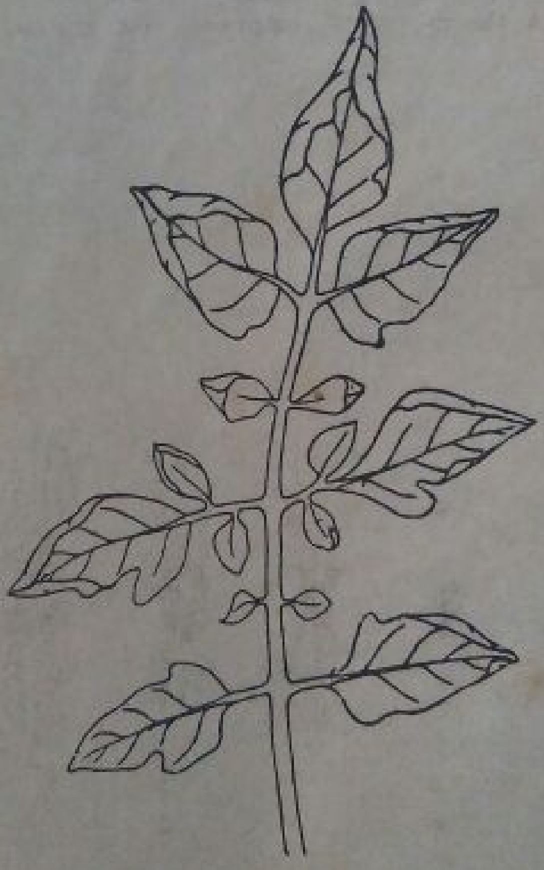


Fig 14.2 Tomato leaf showing potassium deficiency

in their susceptibility to root-rotting organisms.

CALCIUM

Calcium is required for the formation of calcium pectinate, which is the constituent of the middlelamella in the cell walls. It is involved in the conversion of toxic oxalic acid into calcium oxalate in plant cells and plays an important role in lipid metabolism. It is required also for cell division and cell enlargement, in the translocation of carbohydrates and as an activator for amylase, the enzyme which breaks down starch.

The deficiency of calcium results in chlorosis of the margins of the young leaves leading to their necrosis: the leaf tips of many plants become hooked (Fig. 14.3). The deficiency symptoms first appear in the younger leaves and apices of the plants and causes the death of leaf, stem and root apices. The deficiency also causes chromosomal abnormalities in the cells. Calcium deficiency either suppresses flowering or causes the premature fall of flowers.

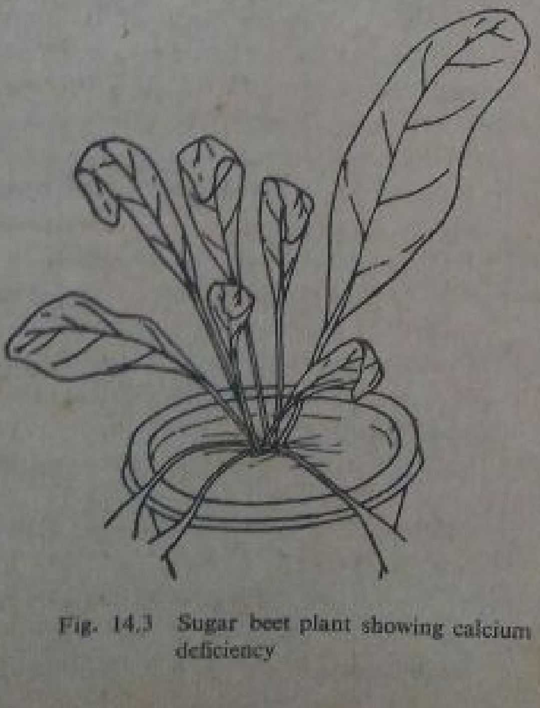


Fig. 14.3 Sugar beet plant showing calcium deficiency

MAGNESIUM

It is a constituent element of chloro… It acts as an activator for some of the … mes, especially of those concerned … phosphorus metabolism. It plays an im… tant role in respiration, synthesis of fats … is essential for the binding of the compon… of ribosomes.

The deficiency of magnesium results … interveinal chlorosis followed by the form… tion of anthocyanin pigments and in seve… cases leads to necrosis. The symptoms … magnesium deficiency first appear in matu… leaves.

IRON

Iron is required in small quantities … plants and is important in the synthesis … chlorophyll. The role of iron in this proce… is indirect in the sense that it is involved … the synthesis of chloroplast protein thereb… affecting the chloroplast formation. Thus, … also affects the formation of carotenoid… Iron also enters in the composition of cyto… chromes, and ferredoxin compounds whic… participate in the electron transport proce… in plants.

The characteristic symptom of iron defi… ciency is the interveinal chlorosis. Th… symptom may be general or localised to … single leaf or a single branch because of th… limited mobility of iron in the tissues. Th… deficiency symptom first appears in you… leaves.

Micronutrients

MANGANESE

This element is an activator for a numbe… of enzymes particularly involved in th… dehydrogenation and decarboxylation reac… tions during respiration. It is also involve… in the nitrogen metabolism.

The deficiency of manganese occurs … some plants in the young leaves and, … some others in the older leaves, resulting …

chlorotic … veinal re…

ZINC

It is r… acetic-ac… Zinc se… enzymes, … lactic del… genase a… The d… content …

Fig. 14.4 …

...tic and necrotic spots in the inter-... regions of the leaves (Fig. 14.4).

...s required for the synthesis of indole-...-acid (IAA), a plant growth substance. ... serves as an activator for several ...nes, such as alcohol dehydrogenase, ... dehydrogenase, glutamic acid dehydro-...se and carboxypeptidases.

...he deficiency of zinc decreases the IAA ...ent in plants, thereby causing a reduction in the growth. It results in 'little leaf' and 'mottle leaf' conditions in the plants. The deficiency also results in a reduction in the size of internodes and the consequent rosette type of growth.

...g. 14.4 Manganese deficiency pattern on a lemon ... chlorosis.

BORON

It increases the absorption of water and calcium. Boron is involved in the formation of pectin in the walls. Boron is also involved in the translocation of carbohydrates.

The deficiency of boron causes the death of the stem and root apices. Due to the deficiency, leaves exhibit thick texture, curl and become brittle and, at times, the leaf tips become black. The deficiency results in the meagre production of flowers. The disintegration of the internal tissues causing abnormalities like 'heart rot' of beets, 'drought rot' of apples, 'stem crack' of celery and 'water core' of turnip are some other characteristic symptoms of boron deficiency.

COPPER

Copper is a component of several enzymes, such as polyphenol oxidase, ascorbic acid oxidase and, thus, plays a major role in plant metabolirm. It is also a component of plastocyanin a compound involved in the electron transport in photosynthesis.

The deficiency of copper in the tung trees reduces the absorption of carbon dioxide. Its deficiency results in the death of many fruit trees. The young leaves exhibit necrosis at the tip, and then in the margins, resulting in the withered appearance. Its deficiency in the citrus trees results in a disease known as *exanthema* and in cereals and herbaceous legumes, a condition known as the reclamation disease.

MOLYBDENUM

It plays an important role in the nitrogen metabolism of plants, especially in the reduction of nitrate. It is a constituent of the

TABLE 14.1

Concentration of nutrient elements in plant material at levels considered adequate

Element	Concentration	Relative number of atoms with respect to molybdenum
	Parts per million	
Molybdenum	0.1	1
Copper	6	100
Zinc	20	300
Manganese	50	1000
Iron	100	2000
Boron	20	2000
	Per cent	
Sulphur	0.1	30,000
Phosphorus	0.2	60,000
Magnesium	0.2	80,000
Calcium	0.5	125,000
Potassium	1.0	1000,000
Nitrogen	1.5	30,000,000
Oxygen	45	35,000,000
Hydrogen	6	60,000,000

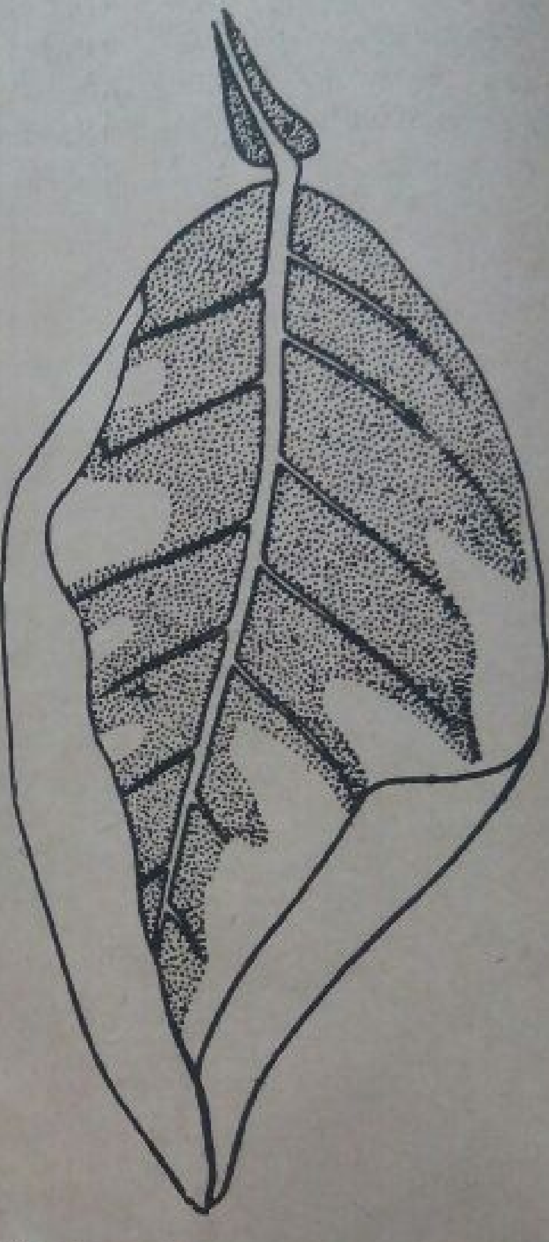


Fig. 14.5 Lemon leaf showing in curled margins and marginal and interveinal necrosis produced by molybdenum deficiency.

enzyme nitrate reductase. It is also involved in nitrogen metabolism. Its deficiency results in a fall in the ascorbic acid content in the plants.

The deficiency of molybdenum results in mottling and necrosis (Fig. 14.5) first in the older leaves and then extends to the younger leaves. In cauliflower, the expansion of the leaf lamina is suppressed resulting in the 'whiptail' condition. Its deficiency also results in the abscission of flowers.

Thus, the micronutrients (except boron) even in low concentration are required either as activators or as integral parts of enzymes. The concentration of nutrient elements which are considered adequate for the plant growth are given in Table 14.1.

EXERCISES

1. What is meant by plant mineral nutrition? What elements are important in plant mineral nutrition?

CHAPTER 15

Stem—Structure and Function

THE stem is the aerial part of the axis of a plant which bears leaves, buds and flowers. The stem which, together with the leaves, is referred to as the shoot system, develops from the shoot apex of the embryonic axis. The principal function of the stem is to expose the leaves to sunlight in order that they can carry out photosynthesis. It also serves to supply nutrients and water to the various regions of the plant.

Primary Structures of the Stem

The initial growth of a plant resulting from the apical meristems is called the *primary growth* and forms the *primary plant body* and its tissues, the *primary tissues*. A tissue is a complex of cells of common origin. All the cells in a tissue may have the same structure and function (simple tissucs) or may have cells of different forms and even different functions (complex tissues). Fig. 15.1 shows the structure of non-vascular tissues.

The primary plant body consists of three-tissue systems, the epidermal, ground and vascular systems, which are developed from the protoderm, ground meristem and procambium, respectively.

DICOTYLEDONOUS STEM

The primary structure of a dicotyledonous stem may be well understood by using sunflower as an example. The stem is divided into four regions, the epidermis, cortex, vascular system and pith (Fig. 15.2).

Epidermis

Externally, the stem is covered by the epidermis which consists of a single layer of compact rectangular living cells (Figs. 15.2 and 15.3). The outer layer is covered by the cuticle and contains multicellular hairs (Fig. 15.2B). A few stomata are present in epidermis. The functions of the epidermis are the protection of underlying tissues and facilitating the gaseous exchange.

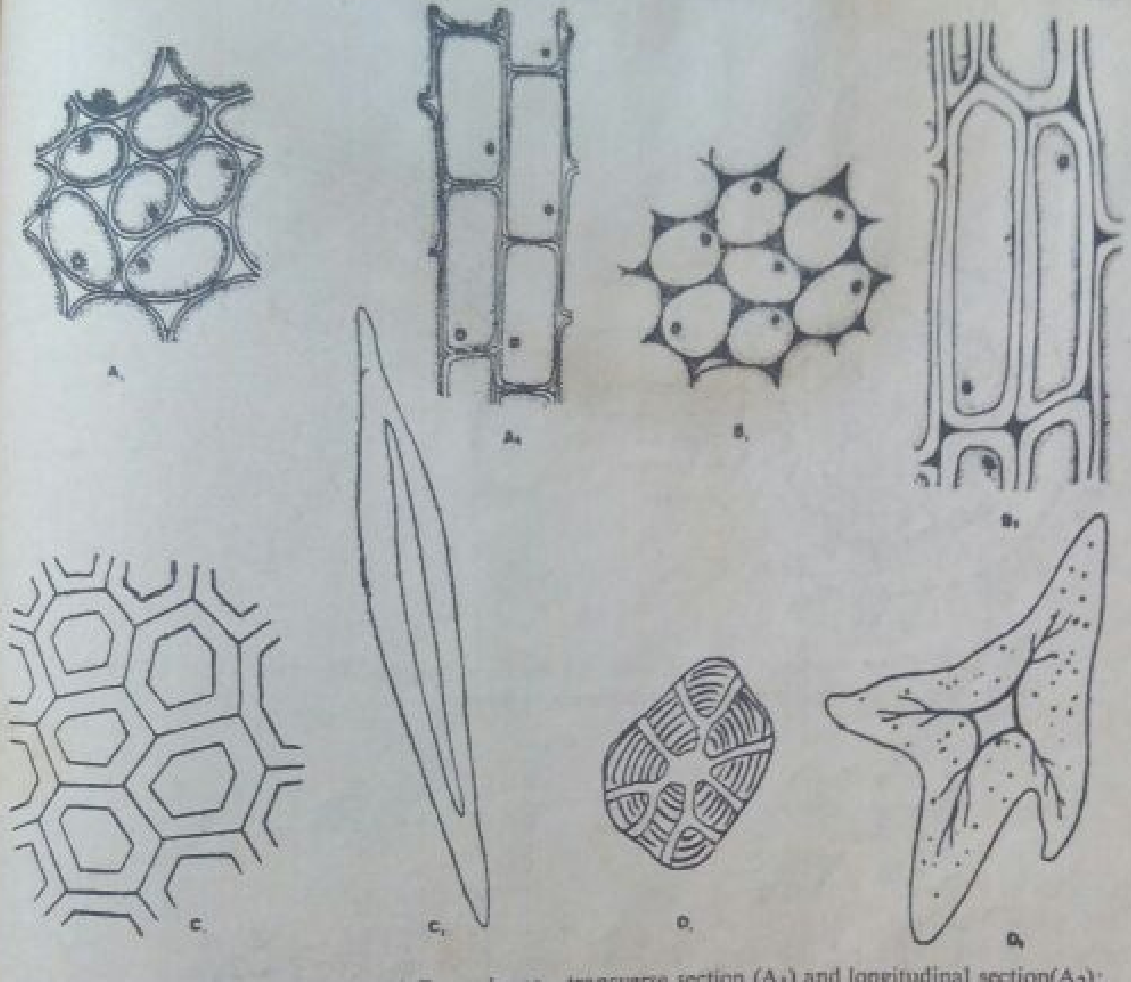


Fig. 15.1 Non-vascular tissues: (A) Parenchyma—transverse section (A_1) and longitudinal section(A_2); (B) Collenchyma—transverse section (B_1) and longitudinal section (B_2); (C) Fibres—transverse section (C_1) and longitudinal section (C_2); (D) Sclereid—transverse section (D_1) and whole sclereid (D_2).

TABLE 15.1
Features of different plant tissues

Name of the tissue	Condition of protoplast at maturity	Structure	
		Transverse section	Longitudinal section
Epidermis	Living	Rectangular cells with thin walls; the outer cell wall thick and cutinised. No intercellular spaces. (The tissue consists of epidermal cells proper, guard cells and trichomes.)	Rectangular
Parenchyma	Living	Polyhedral cells with thin walls. Intercellular spaces present. Consists only of one type of cells.	Oblong
Collenchyma	Living	Polyhedral, thick non-lignified walls, unevenly thickened. Intercellular spaces usually absent. Consists of only one type of cells.	Elongated
Sclerenchyma	No protoplast	Polygonal, thick lignified cell walls and uniformly thick classified into two groups: (1) Fibres; (2) Sclereids	Fibres: elongated with tapering ends. Sclereids: short and oblong

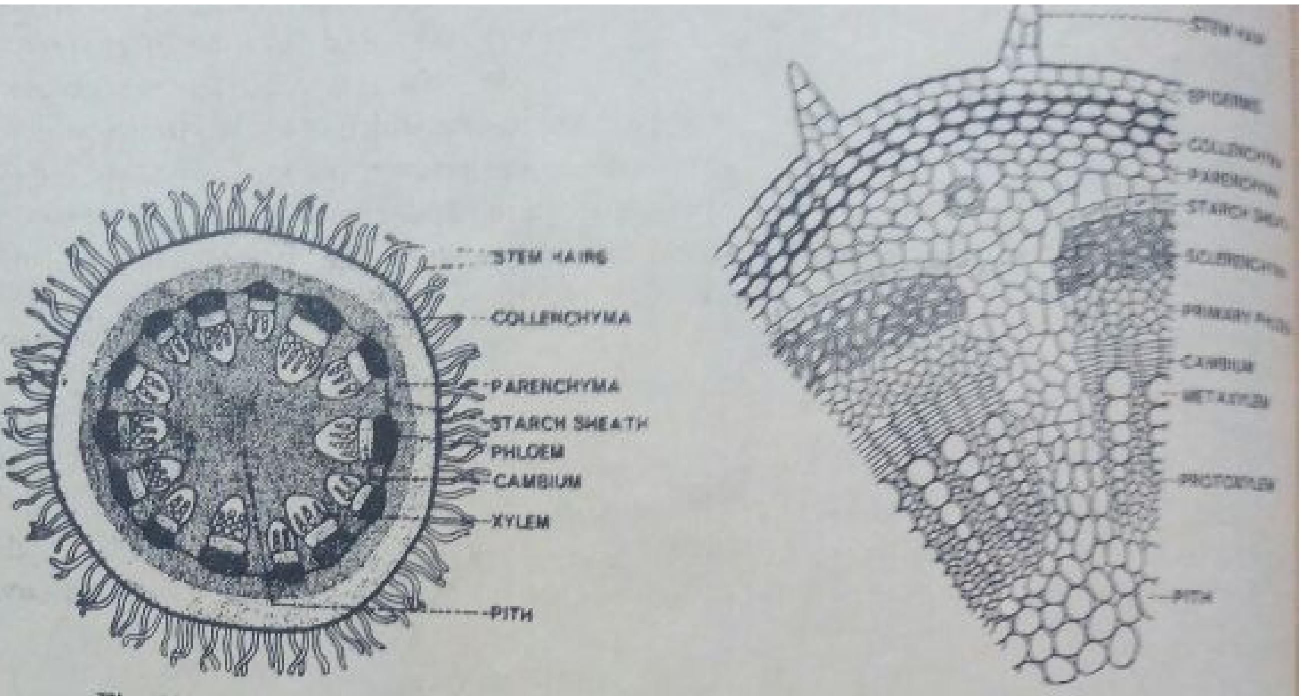


Fig. 15.2 Transverse section of a young dicotyledonous stem: (A) Ground plan; (B) Part as seen under high power of the microscope.

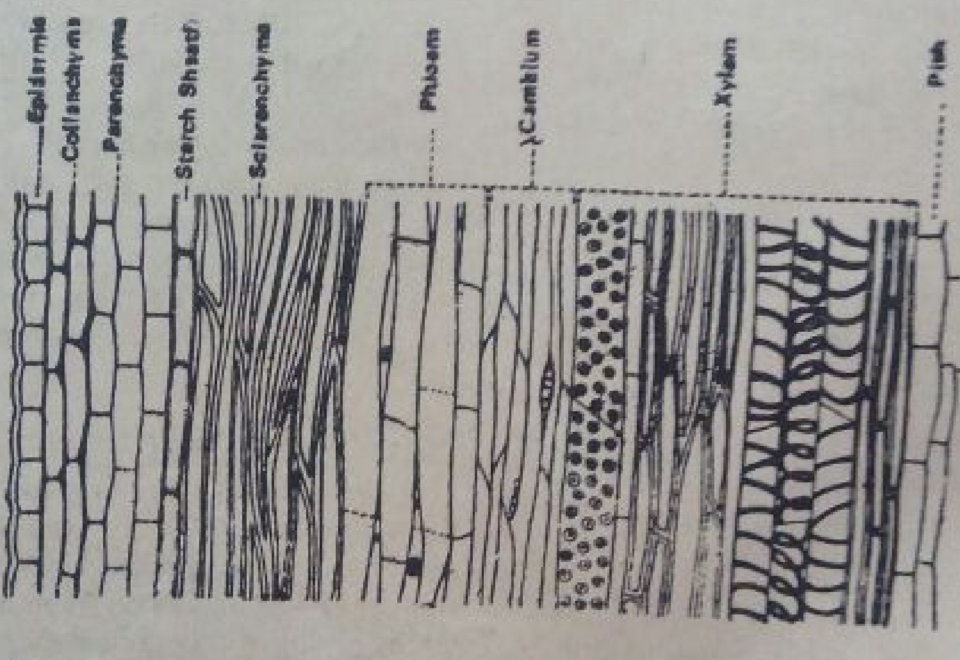


Fig. 15.3 A longitudinal section of a young stem (only a portion is shown).

Cortex

This is the region between the epidermis and the vascular system (Figs. 15.2 and 15.3) and consists of different cell types. Beneath the epidermis, the cortex consists of four to six layers of the collenchyma with the corners of the cells thickened. These cells provide strength and support to the stem. Underneath the collenchyma are present a few layers of parenchyma cells which constitute the bulk of the cortex. The cells are living, thin-walled and with intercellular spaces. The parenchyma of the cortex stores food materials. The innermost layer

the cortex is known as the *endodermis* and consists of a single layer of compact barrel-shaped living cells forming a hollow cylinder. Strips or bands of lignin and suberin are present in the radial and transverse walls of the endodermal cells. These strips are called the *Casparian strips*. The endodermal cells containing starch are called the *starch sheath*.

Pericycle

Pericycle is the outer boundary of the vascular system and is represented by patches of fibres on the periphery of the vascular cylinder.

Vascular System

The vascular system lies internal to the cortex and consists of strands which run along the vascular tissues with the phloem towards the outside and the xylem towards the inside. These strands of the primary vascular system are known as the *vascular bundles or fascicles* (Latin, *fascis*, meaning bundle). In transverse sections, the vascular bundles are obtusely wedge shaped and they are definite in number (Fig. 15.2). The phloem occurs on one side of the xylem and this type of vascular bundle is known as the *collateral bundle*. In some plants, for example, *Cucurbita*, the phloem occurs on both sides of the xylem and this type is known as the *bicollateral bundle*.

The primary xylem consists of tracheary elements (tracheids and vessel members), xylem parenchyma and fibres. The primary phloem consists of sieve elements (sieve cells and sieve-tube members with companion cells), the phloem parenchyma and fibres. The vessels of the first formed xylem (protoxylem) are narrow and the vessels of the later formed xylem (metaxylem) are large. Protoxylem lies towards the centre of the axis in an [illegible] Details of the structure and functions of the xylem and phloem are described later in this chapter.

In dicotyledons, not all the procambium (the meristem which gives rise to the primary xylem and primary phloem is) utilised for the formation of vascular tissues. At the end of the extension growth of the shoot, the procambium is transformed into the cambium, which lies between the xylem and phloem. Such a type of vascular bundle is said to be *open*. The cambium consists of two or three layers of thin-walled cells which are elongated and appear rectangular in sections. Because of its position in the bundle, the cambium is known as the *fascicular cambium*.

Pith or Medulla

Pith is a part of the ground tissue in the centre of the stem enclosed by the vascular system and consists of parenchyma cells with thin walls. Intercellular spaces are present. It stores food materials.

Pith Rays or Medullary Rays

The regions between the vascular bundles (interfascicular regions) are occupied by the plates of parenchyma known as the *pith rays* or medullary rays. They are involved in the radial transport of food, water and mineral salts.

MONOCOTYLEDONOUS STEM

In the stems of monocotyledonous plants the vascular bundles are scattered and no distinct cortex or pith can be delimited. We can study the monocotyledonous stem by taking maize as an example (Fig. 15.4).

Epidermis

It is single layered with, compact, rectangular, living cells. The outer layer is covered by the cuticle. There are no hairs.

Ground Tissues

The ground tissue is not demarcated into the cortex, pith and medullary rays. Beneath

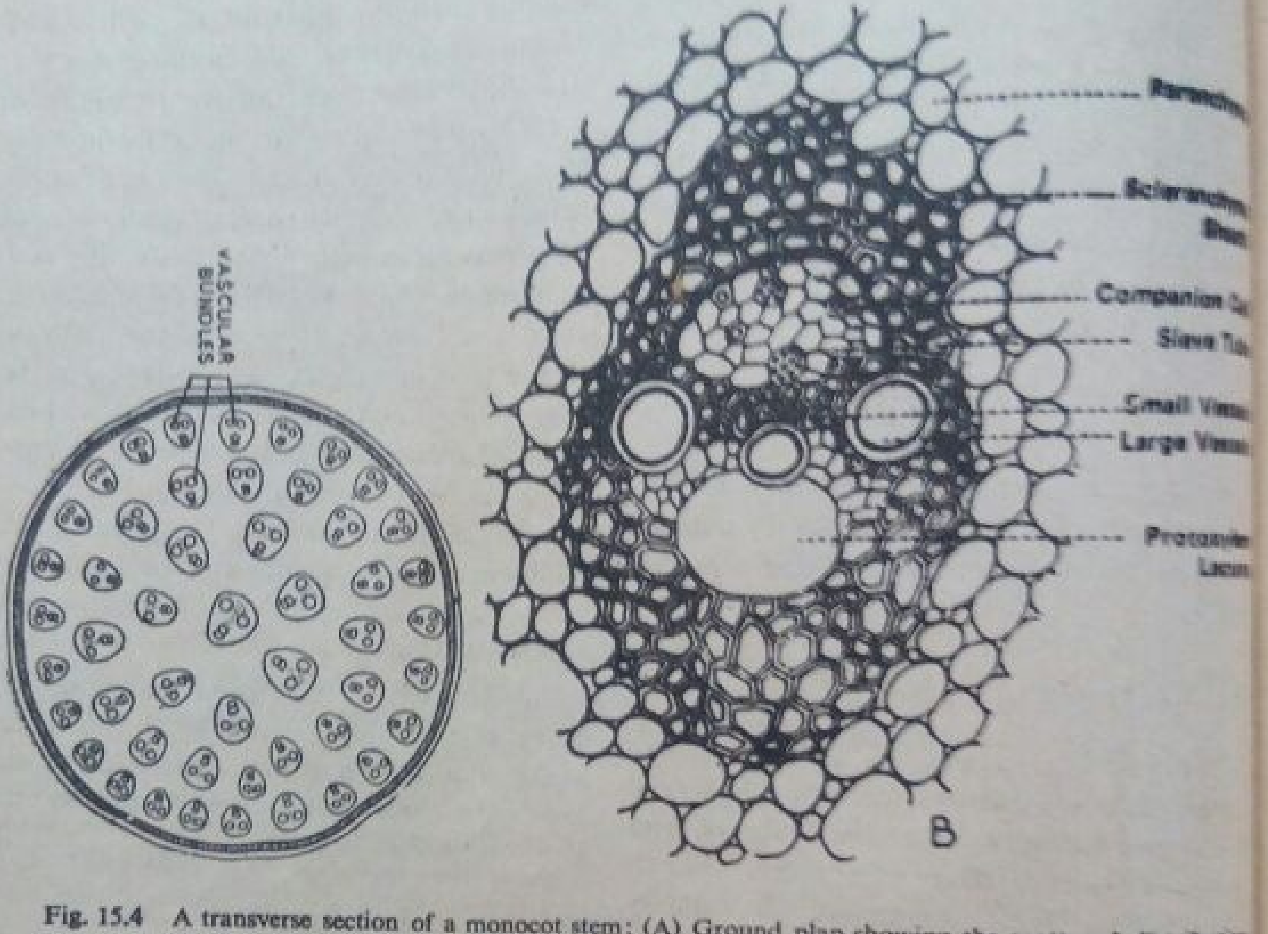


Fig. 15.4 A transverse section of a monocot stem: (A) Ground plan showing the scattered distribution of the vascular bundles: (B) A single vascular bundle as seen under high power of the microscope.

the epidermis, two to three layers of sclerenchyma are present. These layers constitute the *hypodermis*. The remaining ground tissue consists of thin-walled parenchyma cells with small air spaces. The vascular bundles are embedded within this ground tissue.

Vascular System

The vascular system consists of numerous vascular bundles. They are scattered and embedded in the ground tissue without any regular arrangement. The bundles located towards the periphery are small and numerous, while they are big and loosely dispersed towards the centre of the stem. The vascular bundle is collateral and is nearly round in transection. The vascular bundles retain no procambium after the primary vascular tissues mature and this condition is termed as *closed bundle*. The xylem is endarch. The xylem consists of parenchyma, two or three vessels in the protoxylem and two big vessels in the metaxylem. The vessels are arranged in shape and a part of the protoxylem collapses, resulting in open spaces, called *protoxylem lacunae*, surrounded by parenchyma. There is no phloem parenchyma. The vascular bundles are surrounded by a sheath of fibres.

Some of the basic anatomical differences between the dicotyledonous and monocotyledonous stems are summarised in the table on page 135.

It will also be of interest, at this stage, to recapitulate the characteristic anatomical features of the stem and root of an angiosperm. The structure of the primary body shows some fundamental differences between the stem and root, while the secondary

Dicot stem	Monocot stem
Cortex and pith are clearly distinguished.	Cortex and pith are not distinguished, there is only ground tissue.
Endodermis is sometimes present.	Endodermis is absent.
Vascular bundles are few and are arranged in a ring.	Vascular bundles are many and scattered.
Vascular bundles are open and obtusely wedge shaped.	Vascular bundles are closed and oval.
Protoxylem lacunae are absent.	Protoxylem lacunae are present.
Vascular bundles are without sheath of fibres.	Vascular bundles are with a prominent sheath of fibres.
Medullary rays are present.	Medullary rays are not seen.
Secondary growth takes place.	No secondary growth occurs in most of the monocots.

Stem	Root
1. The apical meristem of the stem is truly apical, as it occupies a superficial position.	In the root it is subterminal, for it is covered by the root cap.
2. The relation between the regions of the primary body and apical initials is not precise.	It is often precise.
3. Leaves or even branches arise directly from the apical meristem.	Lateral roots arise independently of the apical meristems.
4. Epidermis has the cuticle, often have multicellular hairs and stomata.	Epidermis is uncutinised and with unicellular root hairs. Stomata are absent.
5. Epidermis is protective.	Epidermis is absorptive.
6. Endodermis is usually not distinct.	Distinct endodermis is present.
7. Usually no distinct region meriting the special name of pericycle occurs between the cortex and the vascular tissues.	Distinct pericycle is present.
8. Vascular system is differentiated in relation to the leaves.	Vascular system differentiated independently of the lateral organs.
9. Vascular tissues are arranged in more or less discrete bundles, collateral or bicollateral and conjoint.	Vascular tissues lack discrete vascular bundles, but develop radially alternate phloem and xylem strands.
10. Xylem is endarch.	Xylem is exarch.
11. Pith is large with radiating medullary rays.	Pith is small or absent.

structure is similar in the two organs. These structural differences are consistent with the diversity of functions carried out by the two organs of the plant.

Secondary Growth in the Stem

The stem increases in diameter away from the apices, due to the activity of the lateral meristems: the *vascular cambium* and the *cork cambium*. The tissues that are produced by the lateral meristems are distinct from the primary tissues and are called the *secondary tissues* and constitute the *secondary body*. Secondary tissues form the bulk of the woody plants and are involved in support, protection and conduction of nutrients and water. The primary growth results in an increase in the length of the axis and the production of lateral appendages, whereas the secondary growth results in an increase in the diameter of the stem. The vascular cambium gives rise to the *secondary xylem*

and *secondary phloem* and the cork cambium gives rise to the cork and phelloderm. As a result of the secondary growth, the outermost primary tissues, the epidermis and sometimes the cortex, are a sloughed off in the older stems. The *periderm* (the collective name for the cork, cork cambium and phelloderm) forms a protective layer.

The secondary growth takes place in the dicotyledons and gymnosperms but is absent in most of the monocotyledons.

In a young dicotyledonous stem, the vascular bundles are separate and are arranged in the form of a ring. In the vascular bundles, the procambium remaining after the formation of the primary xylem and phloem gives rise to the cambium. This cambium arising within the bundles of the primary vascular tissues is called the *fascicular cambium*. The parenchymatous tissue between the vascular bundles in line with the fascicular cambium develops into the *interfascicular cambium*. The fascicular cambium and interfascicular cambium combine to form a continuous cylinder of the vascular cambium (Fig. 15.5).

The active vascular cambium exhibits two types of cell divisions, namely, additive and multiplicative. Additive divisions involve periclinal divisions, resulting in a cylinder of the secondary phloem towards the outside and a cylinder of the secondary xylem towards the inside (Fig. 15.6). More divisions take place towards the xylem resulting in the greater amount of secondary xylem than the secondary phloem in the stems. As a result of this activity, the primary phloem is pushed to the periphery while the primary xylem is pushed towards the centre of the axis. The anticlinal divisions of the vascular cambium result in the circumferential expansion of the cambium.

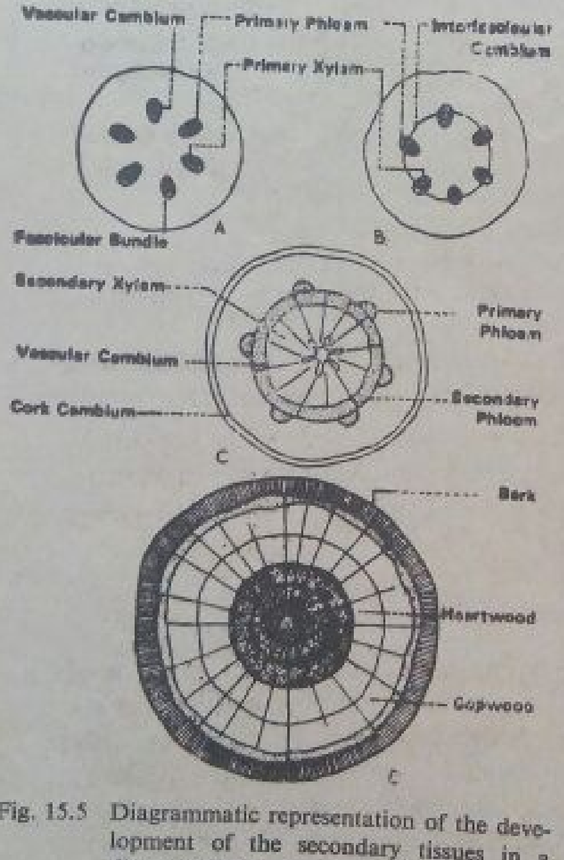


Fig. 15.5 Diagrammatic representation of the development of the secondary tissues in a dicotyledonous stem. A, B, C, and D represent different stages of the secondary growth.

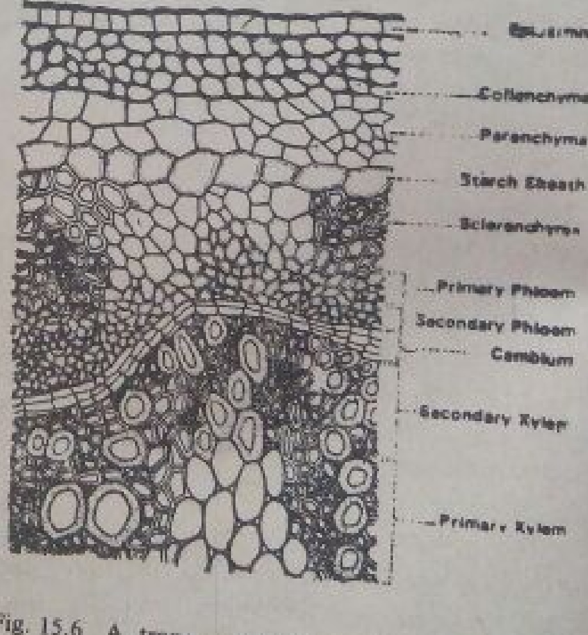


Fig. 15.6 A transverse section of a stem (only a part), showing the secondary phloem and secondary xylem developed from the cambium.

The secondary xylem consists of the rtically-oriented vessel members, namely, acheids, fibres and xylem parenchyma. These are developed from the fusiform inials of the cambium and the horizontally-iented ray parenchyma cells derived from e ray initials. The secondary phloem, likese, consists of the vertically-oriented sieve be members (with companion cells), fibres d phloem parenchyma cells developed from e fusiform initials and the horizontally-iented ray parenchyma cells derived from e ray initials. The xylem ray cells are in ntinuity with the phloem ray cells to form continuous *vascular ray* or simply the *ray*.

The cork cambium (phellogen) develops different depths outside the vascular mbium in different plants; it develops from e sub-epidermal layer, from the epidermal lls or from a few layers deep in the cortex. e cork cambium produces the cork (phelm) tissue towards the outside and the elloderm tissue towards the inside (Fig. 5.7). The three regions together are known the periderm which acts as a protective sue of the secondary origin. In the perirm, there are special structures known as *nticels* permitting the entry of air into the ternal tissues.

The xylem and phloem are the conducting sues and constitute the vascular system of plant. The xylem is associated with the g distance transport of water and minerals d the phloem is for the transport of nutrits from one part of the plant to the other, e distance involved, at times, being more an 30 metres.

Xylem—Structure and Function

The xylem is a complex tissue, consisting different types of cells, living and non-livg, as follows:

(1) *Tracheary elements, tracheids and vessels* for conduction of water and minerals.

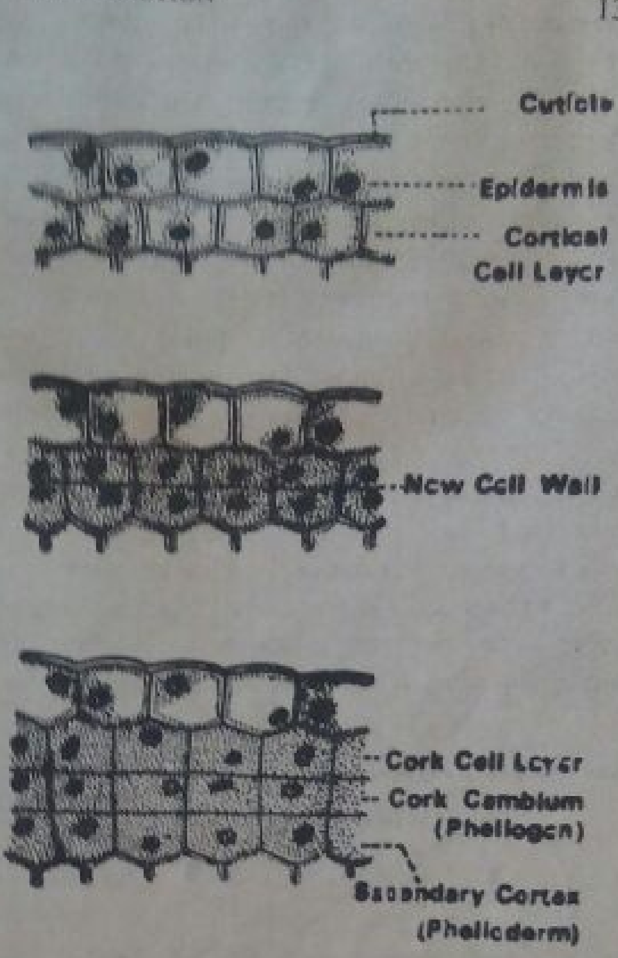


Fig. 15.7 A portion of a dicotyledonous stem, showing the formation of the periderm.

(2) *Parenchyma cells* concerned with various vital activities.

(3) *Fibres* concerned with support.

The xylem is classified into two categories, namely, the *primary xylem* and the *secondary xylem*.

THE PRIMARY XYLEM

The xylem associated with the growth of the primary plant body is called the primary xylem. It develops from procambium. The primary xylem consists of the tracheary elements, tracheids and vessel members, fibres and parenchyma cells. The parenchyma of the primary xylem is not organised into axial parenchyma and ray parenchyma, as in the secondary xylem. There are no rays in the primary xylem.

Two types of tracheary elements, *tracheids*, and *vessel members* are present both in the primary and secondary xylem. The fully-developed tracheary elements are elongated having lignified secondary walls and are without any protoplasm. One difference between the tracheids and the vessel members is that the perforations (openings) at the ends of tracheid cells are absent, whereas the vessel members have perforations at the two ends. The vessel members are joined by their perforated ends to produce continuous tubes known as the *vessels*. Thus, there is continuity of adjacent vessel members through perforations. The continuity between the overlapping tracheids is maintained through the thin portions of the cell walls separating pit-pairs on their common walls. In a vessel member, the wall area bearing the perforation is known as the *perforation plate*. If the perforation plate bears only one perforation, it is called the *simple perforation plate* and if it bears several perforations, it is called the *multiple perforation plate*.

Deposition of the secondary wall of the tracheary elements of a vascular bundle varies in its distribution (Fig. 15.8). In the first-formed primary xylem, the secondary wall thickening may be *annular* (in rings) or *helical* (in a spiral fashion). In the later-formed tracheary elements of the primary xylem, the secondary wall thickening takes place in the form of a ladder, known as the *scalariform thickening*. In the still later-formed tracheary elements, the secondary wall deposition occurs in the form of a network and is known as the *reticulate* thickening. In the ontogenetically most advanced tracheary elements, the secondary wall deposition takes place throughout the walls, except at the pits. Such elements are known as the *pitted elements*. In addition to these thickenings, some intermediate types may also occur. In general, the protoxylem shows annular and helical thickenings (sometimes also reticulate), whereas the metaxylem may have helical, reticulate and pitted secondary walls.

Based on the developmental and structural differences, the primary xylem is of two kinds, namely, the earlier formed xylem known as the *protoxylem* (Greek, *protos* means first) and the later-formed xylem known as the *metaxylem* (Greek, *meta* means beyond). The protoxylem occupies a characteristic position in the primary vascular system. If the protoxylem is located towards the periphery of the axis, it is called *exarch* as in the roots (Fig. 13.1), if it is located towards the centre of the axis, it is called *endarch* as in the stems (Fig.15.2) and if it is located in the centre of the xylem strand, it is called *mesarch*.

The vessels of the protoxylem elements are narrow, whereas those of the metaxylem are large. When the primary plant body matures, the protoxylem becomes non-functional. It is stretched and eventually destroyed by the surrounding cells. In the monocotyledons the non-functional protoxylem elements are partly collapsed but not obliterated, resulting in open canals known as *protoxylem lacunae* surrounded by the parenchyma cells. The metaxylem is retained in the plant for long periods. If the plant lacks the secondary growth, the metaxylem is functional throughout the growth of the primary plant body. If the secondary growth is present in the plant, it becomes non-functional after the secondary xylem is produced.

The protoxylem elements usually contain the tracheary elements and parenchyma. The metaxylem may contain fibres, in addition to the tracheary elements and parenchyma. The xylem fibres are classified into two types, namely, the *fibre-tracheids* and *libriform fibres*. The primary xylem contains only one type of parenchyma and the longitudinal sections reveal their axial nature.

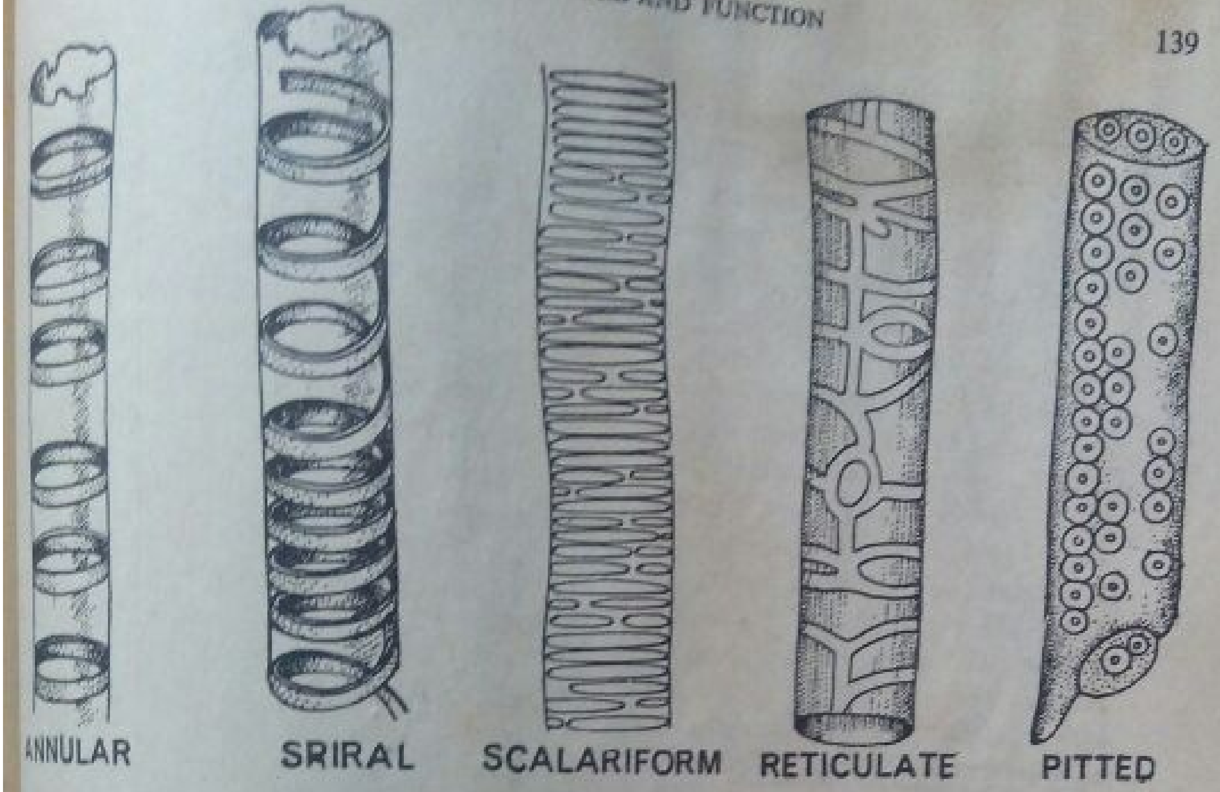


Fig. 15.8 Part of the longitudinal section of primary vascular bundles showing the secondary wall structure in its tracheary elements.

THE SECONDARY XYLEM

The secondary xylem (also termed *wood*) develops from the vascular cambium during the secondary growth of the plant (see Fig. 15.9 and also chapter 13). It consists of tracheids, vessel members, different types of fibres and parenchyma cells (Fig. 15.10). The following table shows the various elements of the secondary xylem and their functions.

TABLE 15.2

Elements of the Secondary Hylems and their functions

Cell types	Main functions
Axial system	
Tracheary elements	
Tracheids	
Vessel members	Water conduction
Fibres	
Fibre tracheids	Support; sometimes storage
Libriform fibres	
Ray system	
Parenchyma cells	Storage and lateral transport

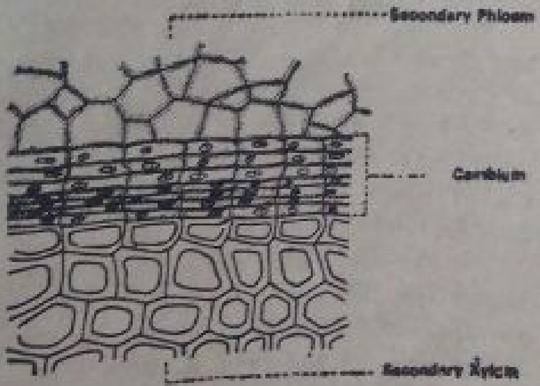


Fig. 15.9 Part of the vascular cambium in a transverse section.

The secondary xylem is characterised by the existence of two systems, namely, the *axial (vertical) system* consisting of tracheary elements, fibres and parenchyma cells and the *ray (horizontal) system* consisting of xylem rays made up of parenchyma cells.

The tracheary elements of the secondary xylem consists of tracheids and vessel mem-

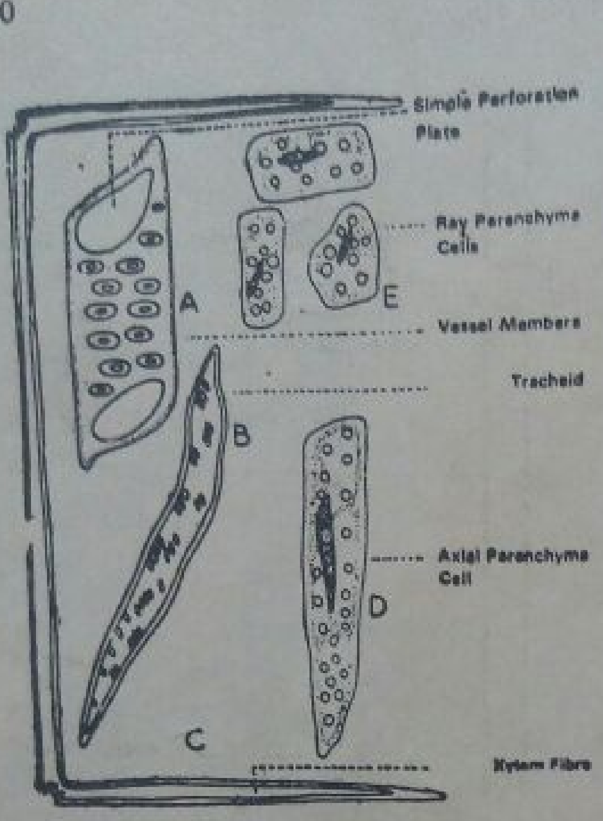


Fig. 15.10 Elements that occur in the secondary xylem: (A) and (B) For water conduction; (C) For support; (D) and (E) For storage and lateral transport.

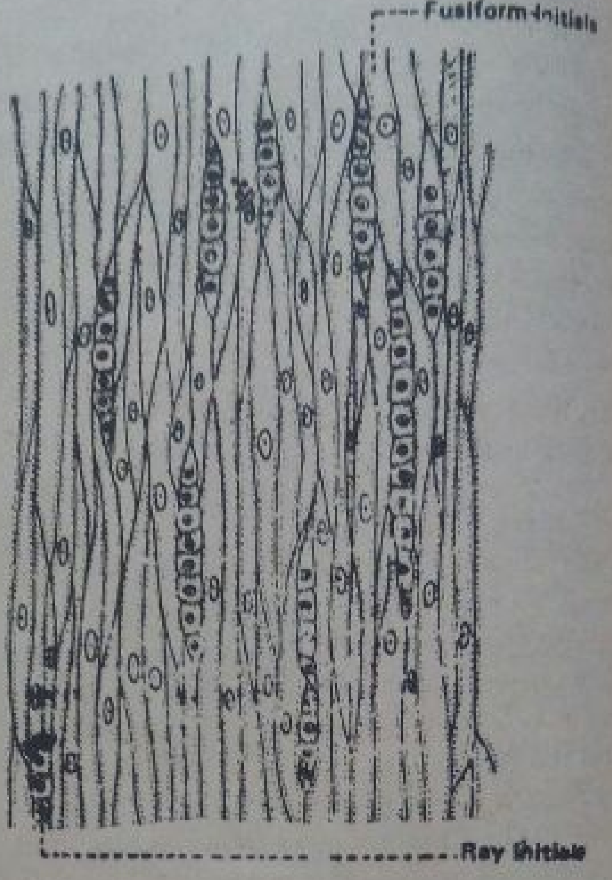


Fig. 15.11 Tangential longitudinal section of the vascular cambium.

bers derived from the fusiform initials of the vascular cambium (Fig. 15.11). The secondary xylem is characterised by pitted elements only. Two types of fibres, fibre tracheids and libriform fibres, are present and are derived from the fusiform initials.

The parenchyma of the secondary xylem occurs in two forms, namely, the *axial parenchyma* derived together with the tracheary elements and fibres from the fusiform initials of the cambium and the *ray parenchyma* derived from the ray initials of the cambium.

GROWTH RINGS

The activity of the vascular cambium is periodic in temperate regions: the periods of active growth alternating with the periods of slow growth. As a result of this alternating activity, ***growth layers*** are formed in the secondary xylem. In a transverse section, they appear as rings and are known as *growth rings*. If a single growth ring is formed each year, it is called an *annual ring*. Each growth ring consists of an inner layer the *early wood*, and an outer layer, the *late wood*. The early wood and the late wood differ in kind, arrangement and size of cells. They also differ in the thickness of the cell walls. The late wood is usually denser and harder than the early wood. The cells of the early wood are larger and have thinner walls than the cells composing the late wood. Usually, more fibres are present in the late wood than in the early wood.

HEARTWOOD AND SAPWOOD

As the secondary growth of a plant progresses, the innermost rings of the secondary xylem become non-functional and inactive without any living cells and are known as the *heartwood*. Usually, various substances,

ch as tannins and crystals, are deposited in ese cells. There is also a gradual or drastic ange in the colour of the cells. In contrast this, the functional and active part of the ondary xylem, outside the heartwood and ide the vascular cambium, is known as the *pwood*. With the growth of the plant, new pwood is added to the plant, transforming e old sapwood into the heartwood. In this y, the amount of heartwood increases year year in the woody stems.

ANSPORT OF WATER

A plant absorbs water through the roots. hen water is absorbed by the root cells, it transferred radially to the tracheary elements (see Chapter 13) and through them it ches all parts of the plant. This process is erred to variously as the *ascent of sap, nduction, transport*, or *translocation of ter*. The bulk of water that is taken up by e plant is lost in the process of transpiration. Only a small quantity, usually less than e per cent, of water absorbed by the plant utilised for plant growth and photosynthesis. Several theories have been postulated the mechanism of the upward movement water in the xylem and they are the *vital, pressure*, and *cohesion-tension* theories. cording to the vital theory, the ascent of is effected by a sort of pumping action the living parenchyma in proximity to the ducting vessels and tracheids. J.C.Bose 23) was one of the advocates of the vital ory. To date, there is no direct evidence vour of this theory.

PRESSURE

e xylem sap exudes from the cut-ends e stem of trees or herbaceous plants. process is the result of the *root pre-* This can be observed if a well- ed herbaceous potted plant is detop- and the stump is attached through ber tube to a capillary tube contain- e water (Fig. 15.12) or a dye solution methylene blue. After some time the

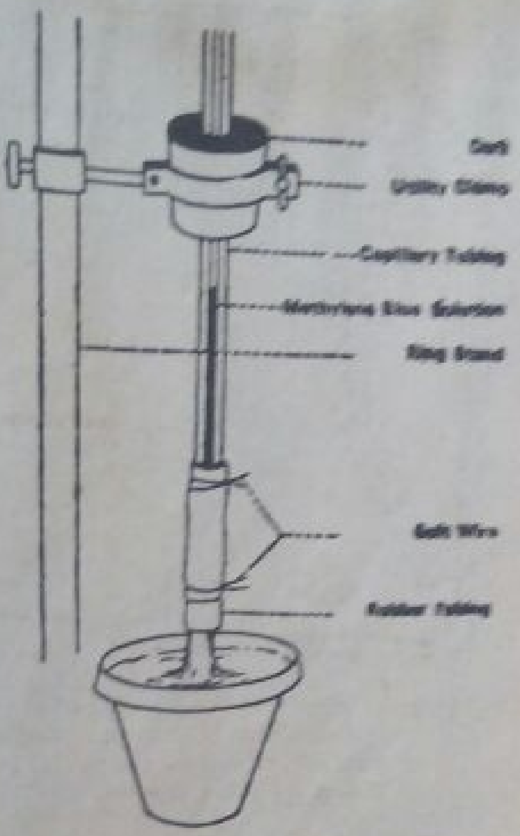


Fig. 15.12 Experiment to demonstrate root pressure.

water (methylene blue) level in the tube rises. This is because the xylem sap, under pressure, exudes from the cut-end of the stump. The pressure developed by this process ranges from three to five atmospheres. It is developed in the tracheary elements of the xylem as a result of the metabolic activities of the root cells and is, therefore, referred to as an active process. The validity of this theory in explaining the mechanism of the upward movement of water has been seriously questioned. The magnitude of the pressure developed is inadequate to raise water to the tops of most trees. The root pressure is even considered to be absent in actively transpiring plants and also in conifers, some of which are the tallest among the trees.

THE COHESION-TENSION THEORY

This theory was advocated by Dixon and Joly (1894) and Askenasy (1895) and is

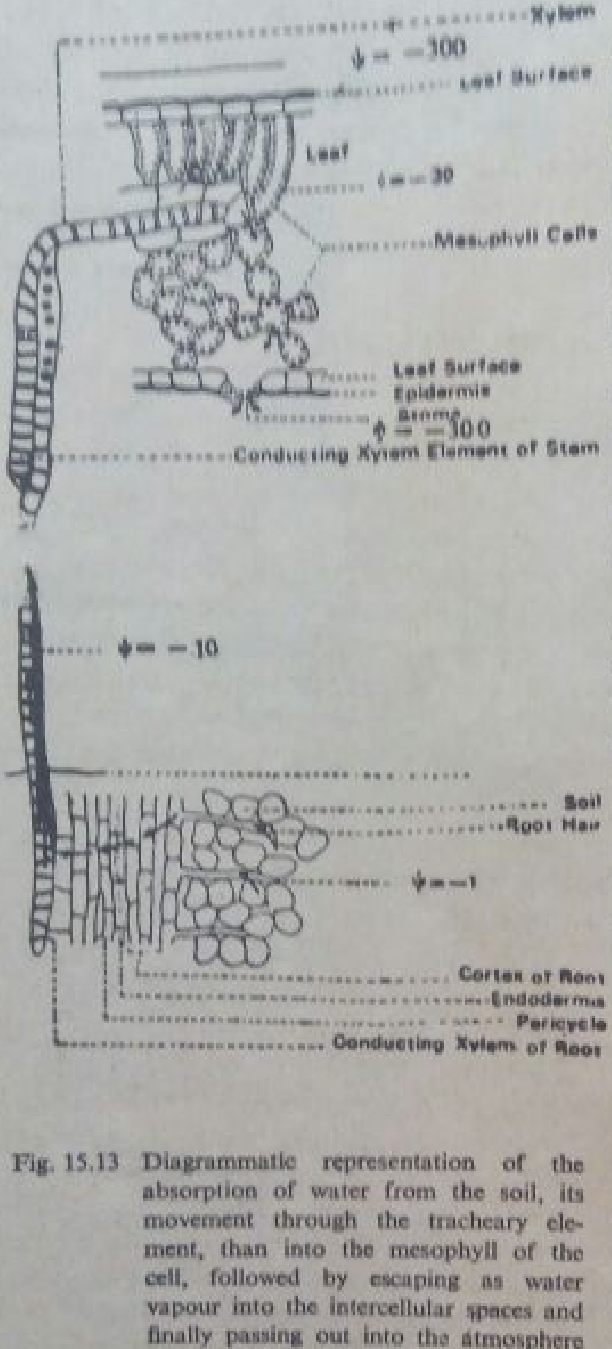


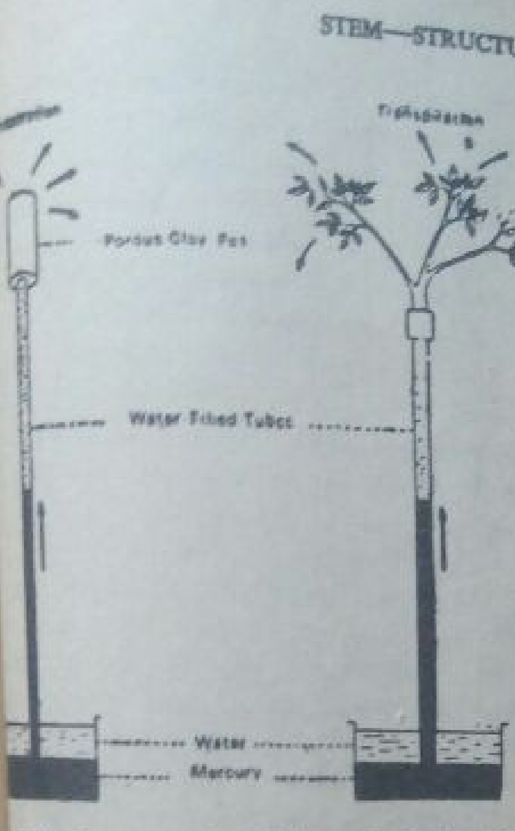
Fig. 15.13 Diagrammatic representation of the absorption of water from the soil, its movement through the tracheary element, than into the mesophyll of the cell, followed by escaping as water vapour into the intercellular spaces and finally passing out into the atmosphere mainly by stomata. The water potential (ψ) gradient is shown in the figure. The water potential of the root hair is high ($\psi = -1$) when compared to the tracheary elements ($\psi = -10$) mesophyll cells ($\psi = -30$) and finally to air ($\psi = -300$). The direction of movement of water is from higher to the lower water potential as shown in the figure. (The value of ψ is given in bars.)

known as Dixon-Joly's Theory of Cohesion or the transpiration pull theory.

As a result of transpiration, water is lost from the surface of the mesophyll cells of the leaves. A reduction in the water content increases the osmotic potential of the mesophyll cells. This results in low water potential in the mesophyll cells. As a result, water from the adjacent cells with the higher water potential is directed towards the mesophyll cells. Such a wateı potential gradient extends up to the contents of the xylem elements of the leaf, resulting in building up tensions in the xylem which ultimately are transmitted to the root through the stem. This process can be explained in the following manner.

Water molecules are strongly attracted to each other. They have a strong force of cohesion. This attraction of water molecules is more if water is confined to relatively long tubes of a narrow diameter, such as the vessel elements. In addition, there is an adhesive force between the walls of the xylem vessels and water. As a result of the cohesive forces of attraction between the water molecules, tension is created in the vessels due to the transpiration pull which results in the upward movement of the water from the roots (Fig.15.13).

The cohesion-tension theory may be demonstrated by the following experiment. A porous pot filled with water is fitted to a long glass tube. It is inverted and the lower end of it is dipped in mercury contained in a beaker (Fig. 15.14). Dry air is passed over it with a fan. The evaporation of water from the porous pot is replaced by the water which is pulled up through the narrow glass tube. Due to this process, tension is created in the glass tube which draws up the mercury from the reservoir below. If the porous pot is replaced by a twig which was cut under water (to stop the entry of air into the xylem elements), the transpiration in the leafy twig results in tension that pulls up the column of mercury from the reservoir



15.14 Demonstration of the cohesion-tension theory: (A) Physical system in which evaporation from the porous procreates the tension required to pull up the column of mercury; (B) Transpiration through the leaves creates the tension required to pull up the column of mercury.

eral evidences are in support of this ry and, hence, it is widely accepted by physiologists.

analysis of the xylem sap indicates t contains most of the mineral elements P, K, S, Mg, Fe, Ca, Cu, Zn, Mo, Mn, ng radioactive tracers, it has also been ed that most of the mineral elements e inorganic form are transported up- along with the water stream through ylem of the root to the other regions of ant.

Phloem—Structure and Function

principal function of the phloem is duction of organic nutrients in plants. hloem is a complex tissue consisting of t types of cells (Figs. 15.15 and), namely, (1) *sieve elements* for conduction of nutrients, (2) *companion cells* concerned with the functioning of sieve elements, (3) *parenchyma cells* for storage of food materials, and (4) *Fibres* and *sclereids* which are for mechanical support. Like the xylem, the phloem is also classified into two categories, namely, the *primary phloem* and the *secondary phloem*.

THE PRIMARY PHLOEM

The phloem associated with the growth of the primary plant body is the primary phloem. It develops from procambium. The primary and secondary phloem consist of the same cell types but, unlike the secondary pholem the parenchyma cells of the primary phloem, are not organised into axial and ray systems. The primary phloem, like the primary xylem, has no rays. The primary phloem consists of sieve elements, sieve cells and sieve-tube members, parenchyma and fibres and sclereids.

The two types of sieve elements, *sieve cells* and *sieve-tube members* are distinguished on the basis of the sieve areas on their walls (Fig. 15.16). The sieve area is a cluster of pores lined with callose (a polymer of glucose residues through which the adjacent sieve elements are interconnected by protoplasmic strands. The wall of the sieve element which

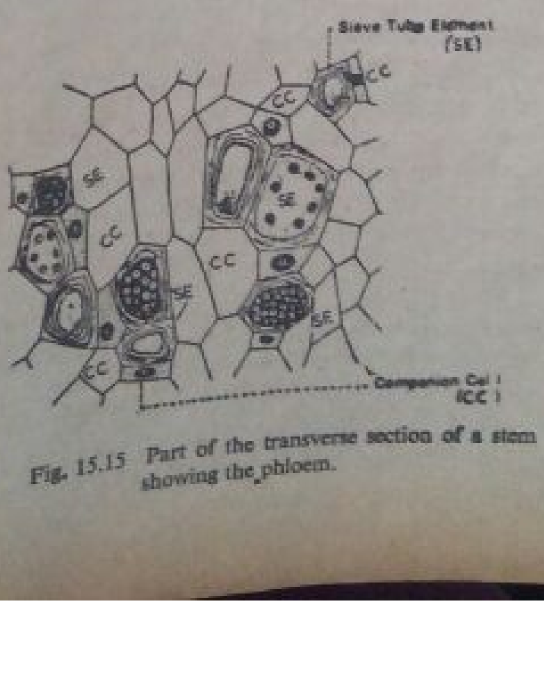


Fig. 15.15 Part of the transverse section of a stem showing the phloem.

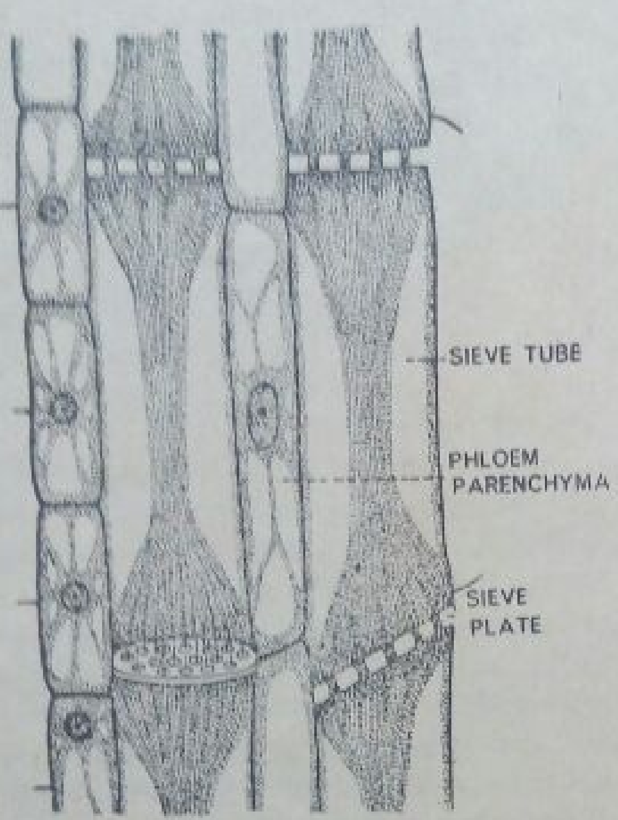


Fig. 15.16 Elements of the phloem as seen in a longitudinal section.

bears the highly specialised sieve areas is known as the *sieve plate* and is a characteristic feature of the angiospermic phloem.

In the sieve cells, the sieve areas are relatively unspecialised in that the sieve areas are not orgnised as sieve plates. The sieve cells are long and slender with tapering ends. In the sieve-tube member, the sieve areas are highly specialised and are organised into structures known as the sieve plates. The sieve plates occur at both ends of the sieve-tube members. The sieve-tube members, which are arranged end to end in long series, connected by their sieve plates are known as the *sieve tubes*. At functional maturity, the sieve-tube member lacks the nucleus but contains cytoplasm.

The sieve-tube members are commonly associated with specialised parenchyma cells known as the *companion cells*. The presence of the companion cells is a characteristic feature of the angiospermic phloem. These cells develop from the same meristematic cell from which its associated sieve-tube member develops. The number of the companion cells associated with a given sieve-tube member varies from one to many, depending upon the plant or, at times, variable in the same plant. The companion cell retains its nucleus at maturity.

The primary phloem, like the primary xylem, is divided into two parts, protophloem and metaphloem. The sieve elements of the protophloem are narrow and inconspicuous. The companion cells are not usually present in the protophloem. During the development of the primary plant body, the sieve elements of the protophloem are crushed by the surrounding cells and disappear. This phenomenon is called *obliteration*. In the protophloem, the sieve elements occur along with the parenchyma and in many plants with the fibre primordia. When the sieve elements are obliterated, the fibre primordia differentiate into fibres. Bundle caps made up of fibres on the outer sides of the vascular bundles of many plants are the result of such a process.

The metaphloem is retained for a longer time in the plant body than the protophloem. The sieve-tube members of the metaphloem are longer and wider than those of the protophloem. The sieve elements of the metaphloem in the angiosperms are only sieve-tube members. In dicotyledons, the sieve-tube members are typically associated with the companion cells and phloem parenchyma. In monocotyledons, the sieve-tube members are associated with the companion cells but the phloem parenchyma cells are not present among these elements. Usually, they are confined to the periphery of the phloem strands. The metaphloem of the dicotyledons usually lacks fibres. In the plants devoid of the secondary growth, as in some herbaceous dicotyledons and in monocotyledons, the metaphloem remains functional throughout the life of the plant. On the other hand, the plants sh

hloem becomes inactive after the form- f the secondary phloem, and may be partially crushed or completely rated.

CONDARY PHLOEM

secondary phloem develops from the lar cambium during the secondary h of the plant. The secondary phloem onsists of axial and radial systems, like condary xylem. The axial system of the yledonous plants contain sieve-tube bers, companion cells, parenchyma cells ibres derived from the fusiform initials e cambium (Figs. 15.11 and 15.16). ray system consists of the ray paren- a derived from the ray initials. The wing table summarises the cell types and functions in the secondary phloem of a yledon.

TABLE 15.3
Elements of the secondary phloem and their functions

Cell types	Main functions
l system	
e elements	
e-tube members	Conduction of food material
h companion cells)	(especially longitudinal)
erenchyma cells	
res	Support; sometimes storage
reids	
l system	
chyma cells	Storage and lateral transport

e structure of the sieve-tube member is r to that described in the primary m. The sieve-tube members are associ- with the companion cells. The secondary m contains fibres. The fibres may occur in bands or scattered in the secondary m. Sclereids may also occur, both in ctioning and non-functioning phloem. e secondary phloem, the parenchyma as two systems, namely, the axial and the ray system. The parenchyma of the axial system is known as the *axial phloem parenchyma*. The parenchyma of the ray system is known as the *ray parenchyma* which constitutes the phloem rays. The ray initials of the cambium produce cells both towards the xylem and phloem, so that the xylem and phloem rays are continuous. *In the secondary phloem, the growth rings are not distinct.*

The duration of activity of the secondary phloem, in most of the dicotyledons, is restricted to the phloem that is produced in the last growing season. That part of the secondary phloem in which the sieve tubes are no longer conducting the food material is known as the non-functioning phloem.

TRANSPORT OF ORGANIC SUBSTANCES

Earlier experiments on translocation were carried out by Marcello Malpighi (1675). The experiments concerned with the removal of a ring of bark (which contains the phloem from around the stem of a tree without removing the xylem (Fig. 15.17). It was observed that this girdling blocked the movement of food materials down the stem, resulting in a swelling of the tissues above the ring.

These experiments indicated that food materials, being the products of photosynthesis in the leaves, moved to the roots through the phloem tissue. Several other experiments using aphids, viruses and radioactive tracers confirmed that the transport of food materials takes place through the phloem.

Modern studies on the transport of food substances have revealed that the sap in the phloem contains five to ten per cent sugar (mainly in the form of sucrose) and also some other organic substances like amino acids and growth regulators. Ringing experiments were performed on the various parts of a plant. For example, removing a strip of bark from around the leafy branch connected to a developing fruit results in the accumula-

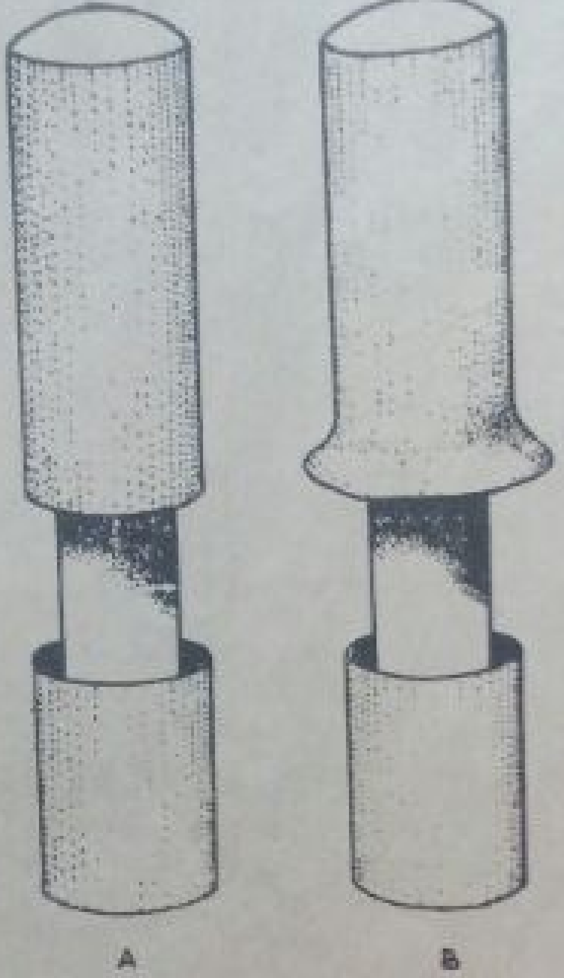


Fig. 15.17 Girdling experiment : (A) A shoot removed with a ring of bark leaving the xylem intact; (B) Swelling of the upper side of the ring after a few weeks. This experiment demonstrates that Girdling (in which the phloem alone is removed) blocked the movement of food material from the leaves downward, indicating that the phloem is the tissue through which the movement of food materials takes place.

tion of sugars on the side of the leafy branch. This indicates that the food materials have moved from 'source' to 'sink'. The movement of food material through the phloem takes place from the leaves (source) to the sites of utilisation, such as storage organs or growing regions (sink). Growing roots, shoot tips and developing fruits are some of the examples of sink. The transport of food material to the roots takes place by the downward movement, whereas it takes place by the upward movement from the leaves to the fruits and shoot tips. Since the major part of transport in plants is towards the roots, most of the studies are concerned with the downward movement of food materials from the leaves to the roots.

Two *hypotheses* have been postulated to explain the mechanism of the *phloem* transport of assimilates: (*i*) the mass or pressure flow hypothesis and (*ii*) the cytoplasmic streaming hypothesis.

THE MASS FLOW HYPOTHESIS

Munich proposed the mass flow hypothesis: the transport of food material through the phloem occurs along the concentration gradients between the sources of food material, 'source' to the sites of utilisation, 'sink'.

Carbohydrates produced during photosynthesis in the mesophyll cells of leaves occur in translocatable form, the sucrose. The presence of sucrose in the cells increases the osmotic concentration of the cells, as a result of which water from the xylem of the nearby veins enters into the cells by osmosis. High turgor pressure, thus, results in the mesophyll cells. During this period, the relatively low sucrose concentration at the sites of utilisation results in low turgor pressure. Thus, a turgor pressure gradient is created, resulting in a mass flow of water along with the dissolved food materials from the 'source' (leaf) to the 'sink' (root) through the phloem (Fig. 15.18). According to the mass flow hypothesis, all the substances in the phloem should move only in one direction. But this is not always a reality.

The mass flow hypothesis can be explained by a simple physical model (Fig. 15.19). Two bulbs A and B made up of membranes permeable only to water are connected by a glass tube C. The bulb A contains sucrose

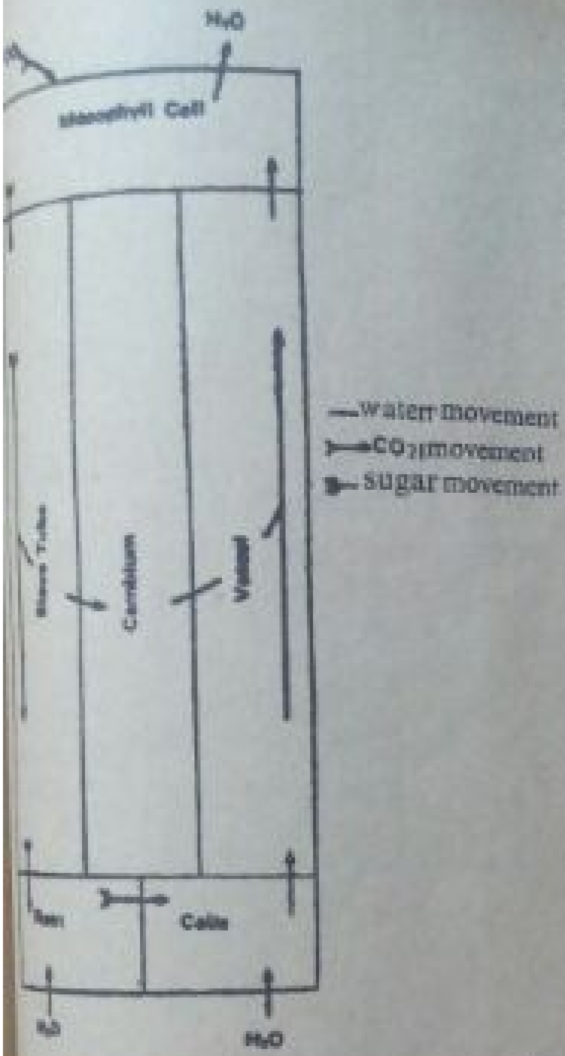


Fig. 15.18 Diagrammatic representation of the mass flow hypothesis.

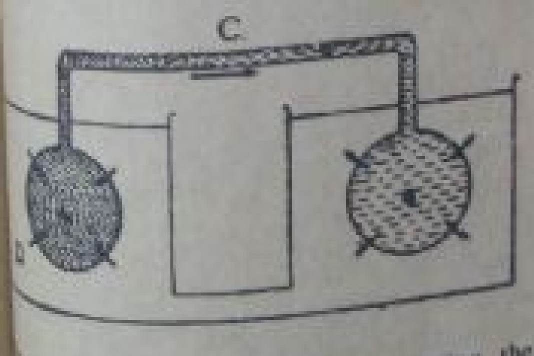


Fig. 15.19 A physical model demonstrating the mass flow in the phloem of cells.

...on and the bulb B water. The bulbs placed in a vessel D containing water. ...enters into the bulb A due to osmosis resulting in turgor pressure which would push water along the tube and then into the bulb B. This process continues until an equilibrium is reached. When sucrose is removed from the bulb B and is replaced in the bulb A, this process will continue through the tube C indefinitely. Here the bulb A acts as the 'source' and the bulb B serves the 'sink'. The mass flow movement of food materials requires energy for 'active transport', or secretion of organic substances from the mesophyll cells into the sieve elements.

Though there are certain objections to this hypothesis, plant physiologists generally accept it as an essential component of the mechanism of the phloem transport.

THE CYTOPLASMIC STREAMING HYPOTHESIS

This hypothesis was suggested by Hugo de Vries in 1885 and was later supported by Curtis in 1929. According to this hypothesis, the transport of substances in the sieve elements takes place by a combination of diffusion and cytoplasmic streaming. Diffusion takes place due to the concentration gradient from one sieve-tube member to the other sieve-tube member through the pores of the sieve plate. Due to cytoplasmic streaming, the substances diffused downward from the cell situated above, and those diffused upward from the cell below are circulated. Diffusion of substances across the sieve plate occurs in response only to their own concentration gradients. This hypothesis accounts for the translocation of two substances simultaneously in the opposite directions (Fig. 15.20).

The mature sieve elements do not show cytoplasmic streaming, hence the phloem transport based on cytoplasmic streaming may take place in young and metabolically active sieve elements only.

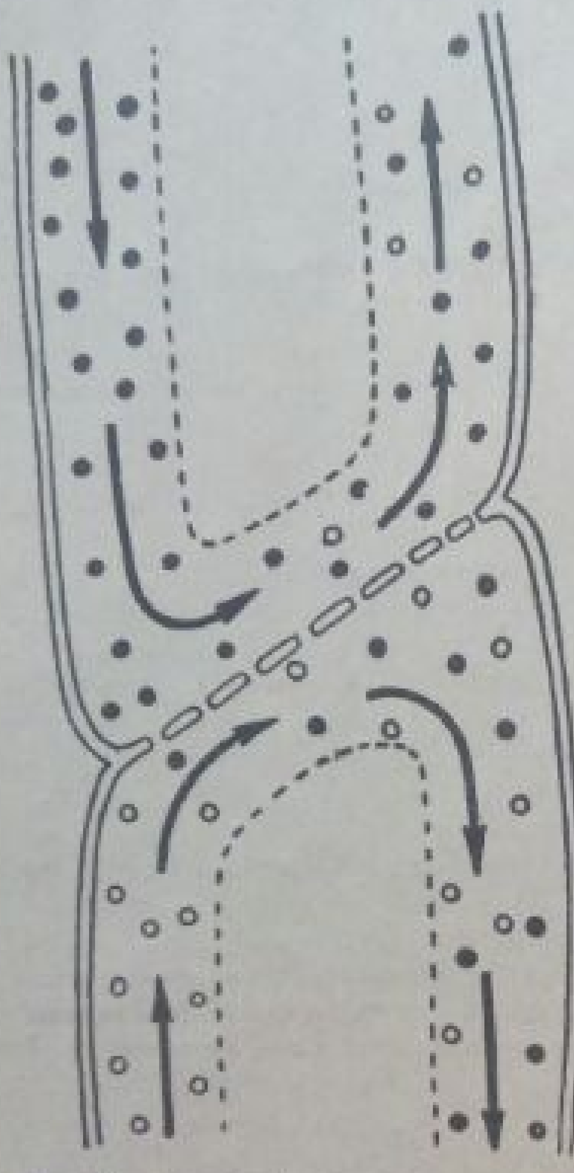


Fig. 15.20 The cytoplasmic streaming theory of solute translocation—a diagrammatic view.

STORAGE

Food materials are manufactured mainly in the leaves and are translocated to the other regions of the plant through the phloem. Some of this is utilised for the growth of the plant, while the excess is stored. Whenever needed, the stored food material is drawn to the regions of necessity again through the phloem. The organs of the plant that store the food materials are called the *storage organs*. The storage of food materials occurs in fruits and seeds. In some plants, roots and stems are modified to perform this function, for example, rhizomes, bulbs, corms and tubers are the modifications of the stem which store the food in the form of carbohydrates, fats and proteins. The conversion of sucrose into starch at the storage region maintains the sucrose concentration low at the storage region and, thus, the concentration gradient is maintained until a sufficient quantity is accumulated. In the storage cells, starch is usually stored in the form of grains. Starch grains are formed in plastid, known as *amyloplasts* (leucoplasts). The growth of a starch grain takes place by apposition of successive shells around a growth centre or hilum. Starch is the common storage material in seeds and cereal grains. Some of the other polysaccharides of storage are hemicellulose and inulin.

Seeds (peanut and sunflower seeds) are the common oil-strong organs of the plant. Carbohydrates are transformed into fats in the developing oil seeds. The derivatives of hexose sugars are the main precursors of the synthesis of fat.

Legume seeds, like soyabeans, peas and pigeon peas, store large quantities of proteins. During the development of a seed, soluble nitrogenous compounds are transported into the seed from the parent plant where they are utilised for the synthesis of storage proteins. In the seeds, proteins are stored in the form of protein bodies (or aleurone grains).

The mobilisation of each reserve substance is brought about by the action of specific enzymes. Thus, starch is hydrolysed into glucose by amylase, inulin into fructose by inulase, fat into fatty acids and glycerol by lipases and protein into amino acids by proteolytic enzymes.

EXERCISES

What is meant by the primary plant body? How is it formed?

Describe the structure of a dicotyledonous stem.

What is a tissue? Name the tissues present in the primary plant body. What are their functions?

Describe the structure of a monocotyledonous stem.

What are the main differences between a dicotyledonous and a monocotyledonous stem?

Compare the anatomical features of a stem and root.

What is meant by the secondary growth? What are the meristems that are responsible for the secondary growth?

Describe the process of secondary growth in a dicotyledonous stem.

What is the origin of the xylem? What are the different cell types that occur in the xylem? What are their functions?

Describe the various types of patterns of the secondary wall thickening in the primary xylem.

Distinguish between the primary and secondary xylem.

What is root pressure? How do you demonstrate it?

Explain the cohesion theory of ascent of sap in plants.

What is the origin of the phloem? What are the different cell types that occur in the phloem? What are their functions?

Distinguish between the primary and secondary phloem.

Explain the mass flow hypothesis of translocation of organic substances in plants.

What is cytoplasmic streaming? In what way does it help the translocation of organic substances? What is the evidence against the cytoplasmic streaming hypothesis?

CHAPTER 16

Leaf—Structure and Function

THE shoot system of higher plants consist of two vegetative organs, the stem and the leaf. The stem is cylindrical and vertically-oriented, whereas the leaf is flat, dorsiventral and horizontally-oriented. The leaf consists of a petiole which is cylindrical and stem-like, and an expanded *blade* or *lamina* which is flattened and therefore with upper and lower surfaces. The principal function of the leaf is photosynthesis. The morphology and structure of the leaf is consistent with this function. The large area of the leaf surface is not only oriented and flattened to absorb maximum light, but is also exposed to air for absortion of carbon-dioxide which is available only at a low concentration of 300 parts per million by volume. The leaf possesses a profuse vascular system for transport of water and mineral elements to the photosynthesising cells and to transport the photosynthetic products to other parts. A system of intercellular spaces accommodates and facilitates the absorption of large quantities of carb[on] dioxide. The presence of stomata permi[ts] gaseous exchange with external atmospher[e]. Land plants have a protective cuticle [to] prevent water loss and stomatal pores [to] facilitate gaseous exchange. Light maintai[ns] the stomata open and thus facilitates [the] entry of carbon dioxide. As a consequen[ce] evaporation of water from stomatal po[res] through transpiration is inevitable.

Origin and Development of Leaf

The development of the leaf in most [of] the plants is uniform. The pattern may [be] studied with *Nicotiana tabacum* as [an] example. The development of the leaf [is] initiated on shoot apices as a small swell[ing] on the flanks of the apical meristem ca[lled] the leaf primordium. It contains the mer[i]stematic cells which divide repeatedly [to] give rise to the future petiole, midrib [and] leaf blade.

Structure of Leaf

The leaf consists of the epidermis mesophyll and vascular systems. The structure of dicotyledonous and monocotyledonous leaves is described below.

DICOTYLEDONOUS LEAF

Structure of a Mesophytic Leaf

The typical structure of a mesophytic leaf as seen in transverse section is represented in Fig. 16.1.

Epidermis: The upper and lower surfaces of the leaf are covered by the upper and lower epidermis, respectively. The cells of the epidermis are single-layered and consist of tightly packed rectangular living cells. The epidermal cells lack chloroplasts. The upper epidermal layer is covered by a thick cuticle. Scattered in the epidermis are numerous minute apertures, called *stomata* (singular: stoma) (see Fig. 16.2), each bounded by two guard cells. The aperture of the stoma leads into a substomatal chamber which is contiguous with the intercellular space system of the mesophyll. Each guard cell is kidney shaped in its surface view and its walls are unevenly thickened. The inner walls of the guard cells bordering the aperture are thicker than the outer walls. The guard cells are unique in the epidermis in possessing chloroplasts. In many plants stomata are associated with two or more specialised cells known as the *subsidiary* or *accessory cells*. Stomata may be present in both the upper and the lower epidermis. Usually the number of stomata on the lower epider-

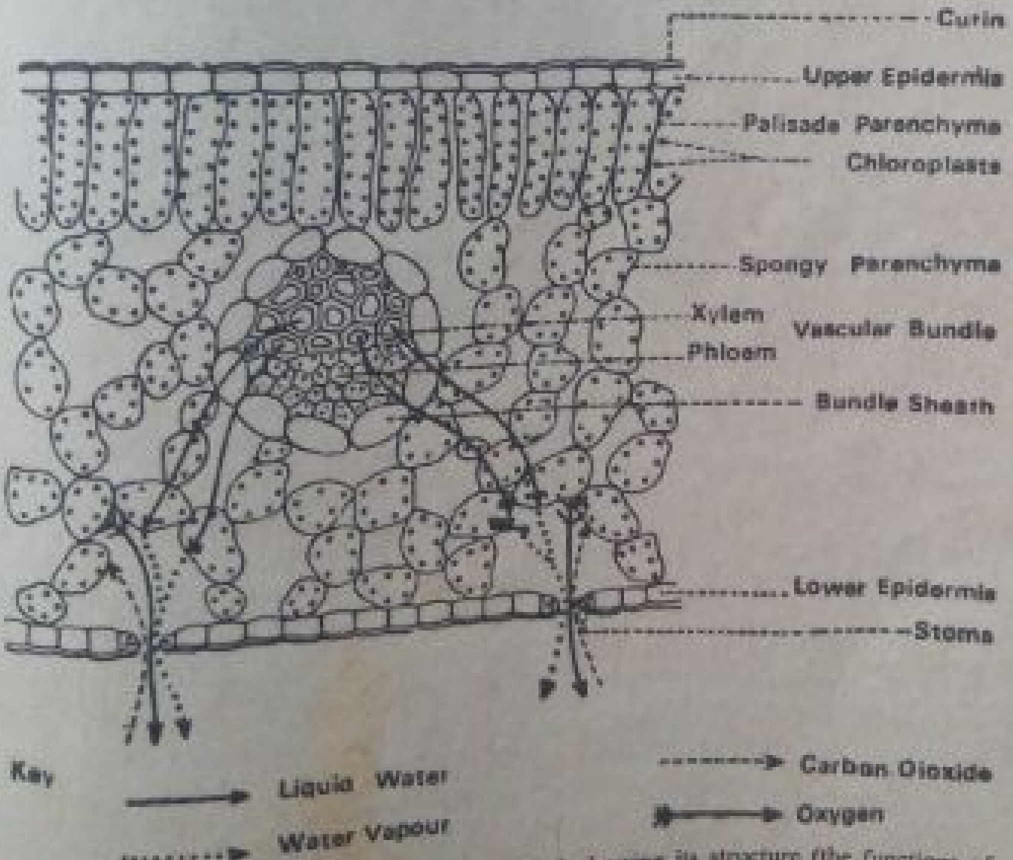


Fig. 16.1 A transverse section of a mesophytic leaf, showing its structure (the functions of a leaf are also shown).

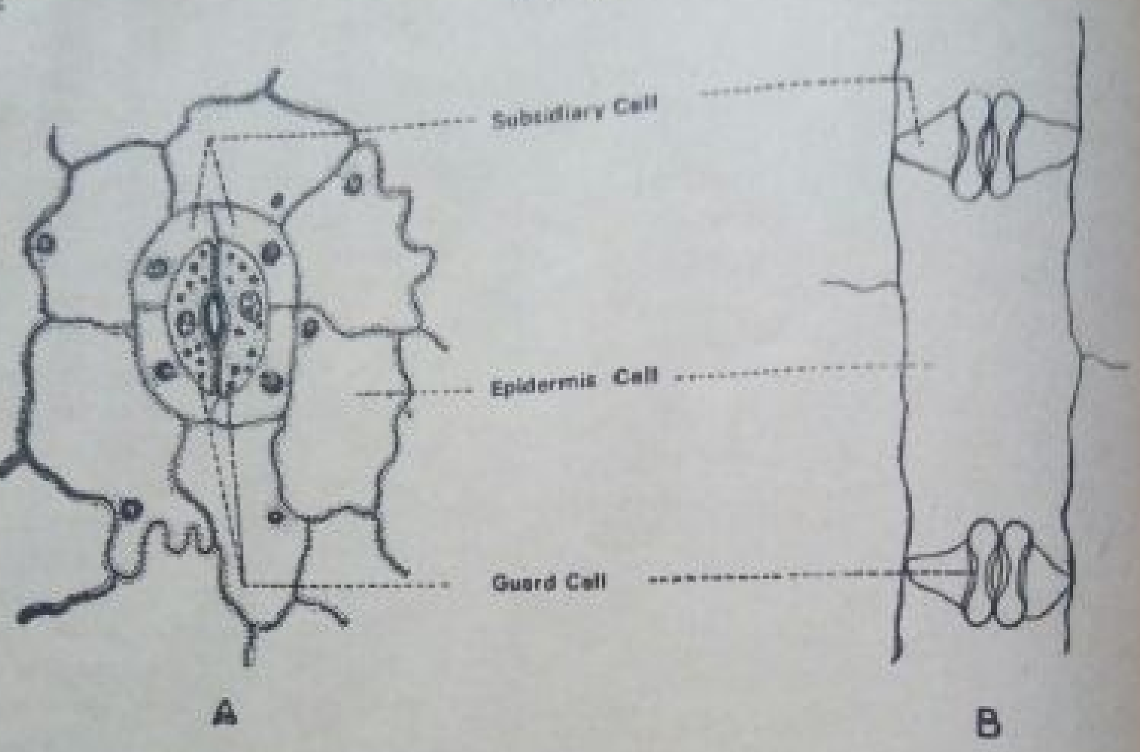


Fig. 16.2 Stomata, surface view: (A) Dicotyledonous; (B) Monocotyledonous

mis is greater than that in the upper epidermis. Stomata are totally absent in the upper epidermis of some plants. The epidermis bears several types of multicellular hairs and is protective in function.

Mesophyll: The ground tissue of the leaf which is enclosed within the epidermis is called the mesophyll. This consists of parenchymatous tissue containing chloroplasts (parenchyma tissue which contains chloroplasts is known as *chlorenchyma* tissue) with intercellular spaces and is specialised for photosynthesis. Mesophyll is divided into regions (a) palisade parenchyma and (b) spongy parenchyma.

(a) *Palisade parenchyma:* The palisade parenchvma occurs immediately beneath the epidermis. The palisade cells are elongated at right angles to the surface and are arranged parallel to one another with or without narrow intercellular spaces. They form one to three layers of cells. The cells contain abundant chloroplasts, hence the upper surface of the leaf appears dark green. The cells are mainly photosynthetic in function.

(b) *Spongy parenchyma:* This occurs below the palisade parenchyma with loosely arranged and irregularly shaped cells associated with large intercellular spaces. The cells here contain fewer chloroplasts than those in the palisade parenchyma. The rich intercellular spaces of this tissue together with the smaller intercellular spaces of the palisade constitute a system of air spaces extending throughout the leaf helping the distribution and diffusion of gases. In addition, the spongy parenchyma is also photosynthetic in function.

Vascular system: A vein is a vascular bundle forming a part of the framework of the vascular system of a leaf. The arrangement of the veins in a leaf is known as venation. Several vascular bundles can be seen in the transverse section of a leaf. Each vascular bundle is usually located about halfway between the upper epidermis and the lower epidermis and consists of the xylem towards the upper side of the leaf and the

...cambium is absent, hence no secondary ...s are formed. The smaller veins of ...leaf are usually surrounded by tightly ...ed parenchyma cells known as the ...dle *sheath*. The bundle sheath cells may ...tain chloroplasts (chlorenchymatous ...dle sheaths i.e., *Boerhaavia diffusa*) or ...y may be devoid of chloroplasts (e.g., ...*flower*). The xylem is meant for con-...ting water and minerals to the leaf and ...e phloem tissue is meant to carry the ...tosynthetic products from the leaf to the ...er parts of the plant.

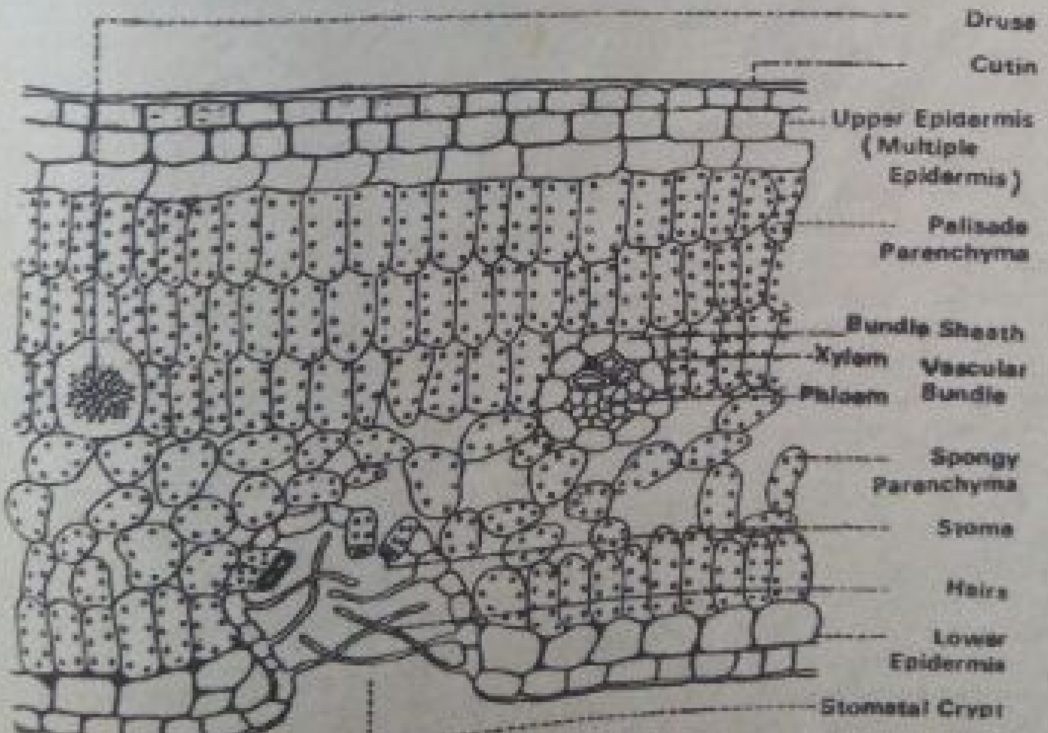
...ucture of *Xerophytic Leaf*

...tain plants, for example *Nerium*, grow ...der high light intensities and very low ...ter content in the soil. As a result they ...hibit several anatomical modifications in ...e leaves which reduce the water loss due ...transpiration.

Epidermis: The cuticle is present both on the upper and the lower epidermis. The epidermal cells are present in three layers. This type of epidermis is known as the multiple epidermis. In the lower epidermis several depressions known as stomatal *crypts* are present. The stomata are restricted to the epidermis that lines these depressions. Such stomata are referred to as the sunken stomata. Numerous multicellular hairs are present in these stomatal crypts.

Mesophyll: The palisade parenchyma occurs both on the upper and the lower side of the mesophyll. Crystals of calcium oxalate (druse) are scattered in the upper palisade layers. The spongy parenchyma and the air spaces in the middle of the leaf are reduced.

Vascular system. The veins consist of the conducting tissues, the xylem and the phloem surrounded by the bundle sheath.



...transverse section of the leaf of *Nerium*, a xerophytic leaf.

MONOCOTYLEDONOUS LEAF

The structure of a monocotyledonous leaf is well illustrated by maize (Fig. 16.4).

Epidermis: The epidermis consists of one layer of compactly placed cells which are without chloroplasts. Some epidermal cells, known as the bulliform cells present in the upper epidermis are large, thin-walled, highly vacuolated and contain mainly water. There are two views regarding the function of the bulliform cells. According to one view, they are concerned with the unrolling of the leaf during its development while the other view states that they are concerned with the opening and closing movements of mature leaves. Stomata are present both in the upper and the lower epidermis. In a surface view, the guard cells of the stomata are dumb-bell shaped (Fig. 16.4). The stomata are associated with subsidiary cells.

Mesophyll: The mesophyll is not differentiated into distinct palisade and spongy parenchyma. The mesophyll cells are rich in chloroplasts.

Vascular system: The vascular bundles of various sizes are arranged in row, with the xylem towards the upper side and the phloem towards the lower side in each vascular bundle. The characteristic bundle sheath around each smaller vein contains chloroplasts arranged in centrifugal fashion. The large vascular bundles are surrounded by sclerenchyma.

Photosynthesis

Photosynthesis (*photos* means light; *synthesis* means putting together) is the process by which green plants manufacture sugar from the carbon dioxide and water utilising sunlight as the source of energy. Photo-

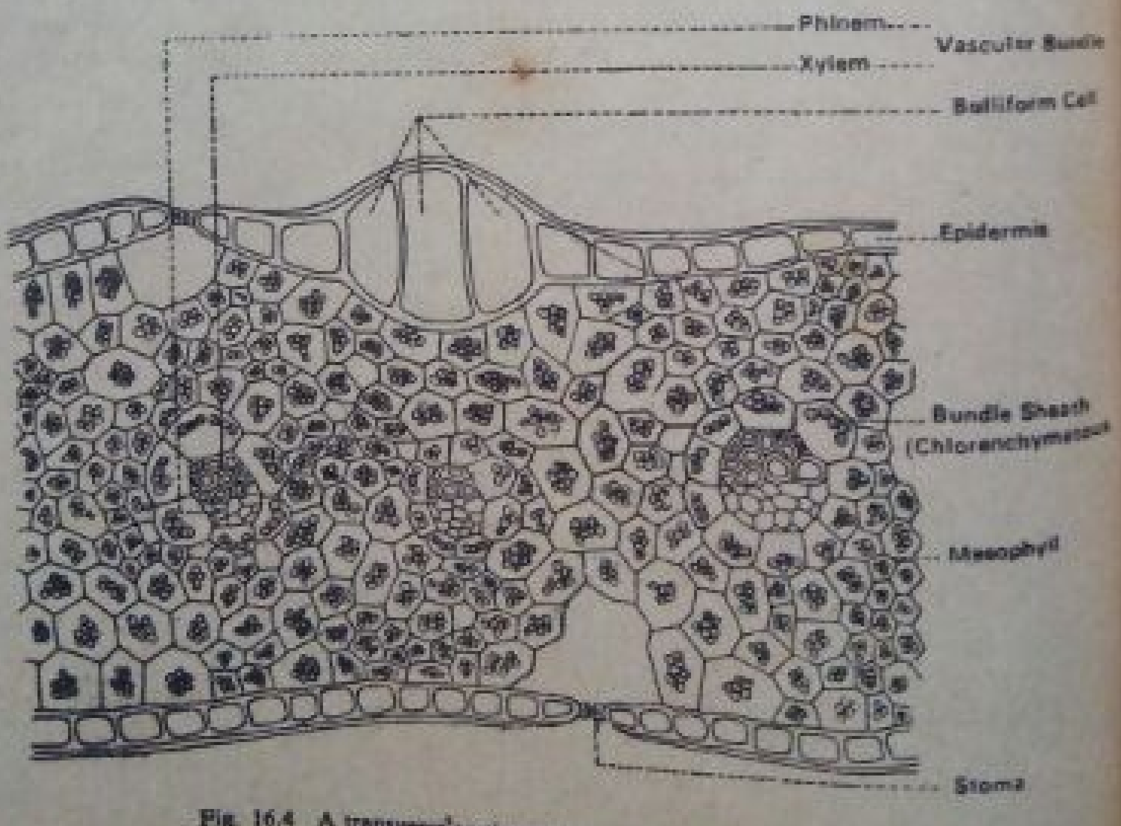


Fig. 16.4 A transverse section of a monocotyledonous leaf (maize).

...thesis is generally represented by the ...lowing equation:

$$CO_2 + 12\,H_2O \xrightarrow[\text{Light}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2 \quad (1)$$

This process is unique to green plants and is the final light energy trapping process ... which all life ultimately depends. In ...dition, green plants are also responsible ... the release of oxygen into the atmosphere.

Historically, it was Stephen Hales in 1727 who recognised that sunlight and air are ...portant for the growth of plants. Joseph ...estley in 1772 recognised that plants ...ve the capacity to renew air that is made ...le by the breathing of animals. Subse...ently in 1779, Jan Ingenhousz showed ...at light was necessary for purification of ...r. The purifying principle given off by the ...nts in light was identified and named as ...ygen by Lavoisier in 1783.

Much of our recent knowledge on the ...echanism of photosynthesis has been ...ained by the use of radioactive isotopes. In ...der to find out whether oxygen evolved ...ring photosynthesis is from carbon ...oxide or water, water containing heavy ...ygen ($H_2{}^{18}O$) in place of natural oxygen ...otope $H_2{}^{16}O$ was used. It was observed ...at oxygen evolved in photosynthesis was ...und to be $^{18}O_2$. When the heavy isotope ...as supplied as part of the carbon dioxide ...olecule ($C^{18}O_2$), the released oxygen was ...O_2. This experiment clearly indicated that ...ygen evolved in photosynthesis is actually ...leased from the water molecule and not ...om carbon dioxide.

Thus water is oxidised in light with the ...lease of oxygen and carbon dioxide is ...duced by the reductant generated in the ...otochemical process.

In 1937 Robin Hill demonstrated the ...lease of molecular oxygen by illuminated, ...olated chloroplasts at the expense of ...duction of oxidising substance such as ferric salt, quinone or indophenol dye, and in the absence of carbon dioxide (equation 2). This process was subsequently named as the Hill reaction.

$$A + H_2O \xrightarrow[\text{Chloroplast}]{\text{Light}} AH_2 + \tfrac{1}{2}O_2 \quad (2)$$

where A represents an oxidising substance.

In 1951 it was observed that NADP could replace the non-physiological substances.

$$H_2O + ADP \xrightarrow[\text{Chloroplast}]{\text{Light}} \tfrac{1}{2}O_2 + NADPH_2 \quad (3)$$

where NADP represents nicotinamide-adenine dinucleotide phosphate.

$NADPH_2$ represents reduced nicotinamide dinucleotide phosphate. NADP comes under a group of organic substances known as coenzymes. They act as donors or acceptors of groups of atoms (H_2) that have been added to or removed from the various substances that participate in photosynthesis, respiration, etc. Other examples of coenzymes are NAD (nicotinamide-adenine dinucleotide) and FAD (flavin adenine dinucleotide).

The Hill reaction represents a separation of water oxidation step from the carbon dioxide reduction phase in photosynthesis and thus also proves that the source of oxygen in photosynthesis is the water molecule.

CHLOROPLAST AND ITS PIGMENTS

Chloroplasts are organelles of the cytoplasm which contain the complete machinery for photosynthesis. In lower plants, chloroplasts are of different shapes and sizes. In higher plants, they are more or less ellipsoidal, approximately 5-10 μ in diameter and 2-3 μ thickness. A single cell may contain 300 or more chloroplasts. The outer chloroplast membrane (envelope) encloses a space consisting of stacked membranous discs or *thylakoids* termed grana distributed in a ground region termed the *stroma*. (Fig. 16.5.)

Fig. 16.5 Chloroplast in cross section as seen under an electron microscope.

The stroma phase is an aqueous or soluble phase containing enzymes that are concerned with carbon reduction, synthesis of proteins and nucleic acids (DNA and RNA). The thylakoid membrane consists of 50 per cent lipid and 50 per cent protein. It contains the light absorbing pigments, the chlorophylls and carotenoids, enzymes and other substances that are concerned with the oxidation of water and the transfer of electrons to an electron acceptor.

Chlorophyll, the unique molecule capable of catalysing the photochemical reactions of photosynthesis, resembles a 'tadpole' in its molecular configuration with a square 'head' of four pyrrole rings containing a magnesium atom in the centre and a long 'tail' of phytol chain (Fig. 16.6). The chlorophyll pigments are green. There are two important chlorophylls—chlorophyll *a* and chlorophyll *b*. Chlorophyll *a* and *b* differ from each other in that chlorophyll *a* has a methyl group on one of the pyrrole rings while chlorophyll *b* has an aldehyde group instead. All the pigments in the chloroplast absorb light quanta or photons at particular wavelengths of the visible light. The curve showing the amount of light absorbed at each wavelength is called *absorption spectrum*. The absorption spectra of chlorophyll *a* and *b* are shown in the figure. They absorb more intensely at blue, violet and red wave lengths. The curve showing the relative rate of photosynthesis at different wave lengths of light is called the *action spectrum* which shows close correlation with absorption spectra of chlorophyll *a* and *b* (Fig. 16.7).

In addition to chlorophyll *a* and *b*, the chloroplast also contains some other pigments like carotene (orange) and xanthophyll (yellow). Carotene and xanthophyll are together known as carotenoids. All pigments other than chlorophyll *a* are called the

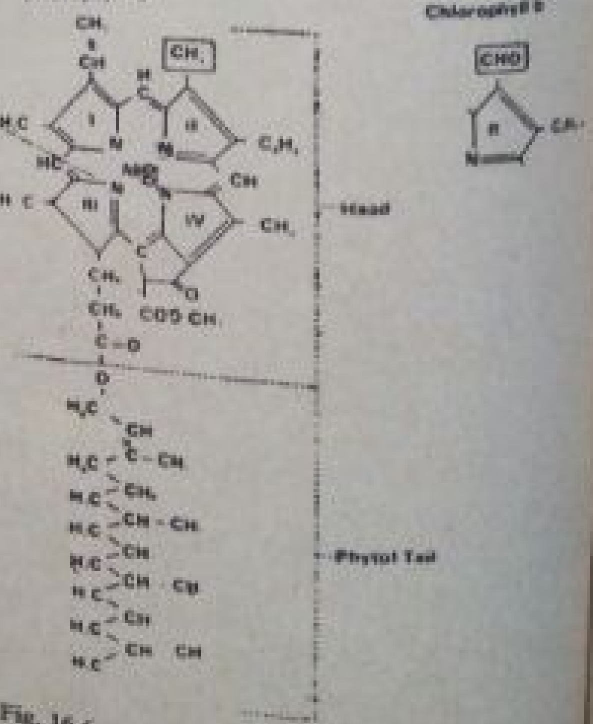


Fig. 16.6 The structure of chlorophyll *a* and chlorophyll *b*

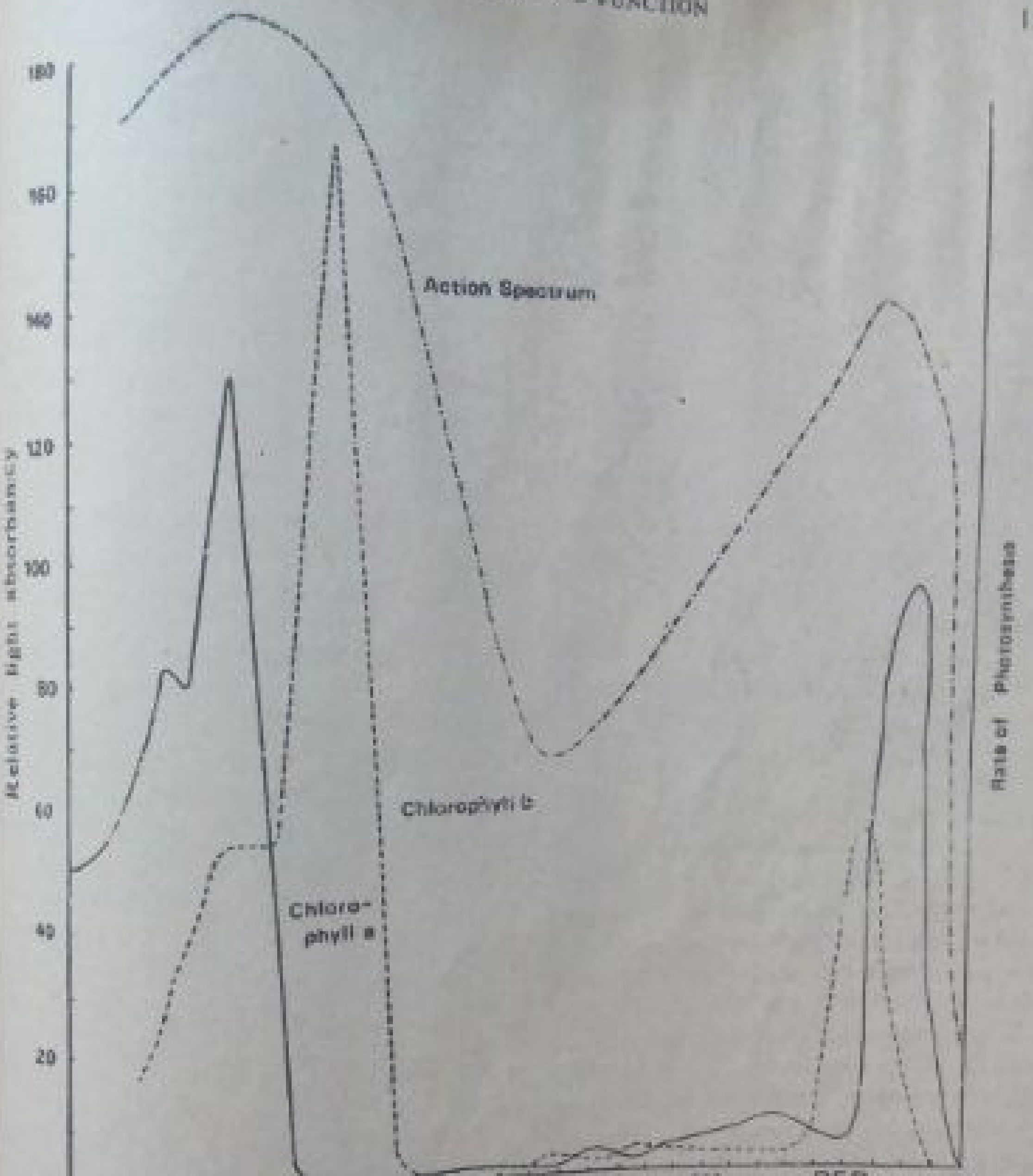


Fig. 16.7 Absorption spectra of chlorophyll *a* and *b* and action spectrum for photosynthesis.

ccessory pigments which ultimately transfer he absorbed light energy to chlorophyll *a*.

o Phases of Photosynthesis

The overall process of photosynthesis nsists of two principal partial reactions. he first is associated with grana of the oroplasts and occurs only in the presence of light. This is referred to as photochemical phase or light reaction. It is concerned with the generation of $NADPH_2$ and ATP (adenosine triphosphate) which constitute the 'assimilating power'. This represents the light or the photochemical phase of photo-synthesis. The second phase is the fixation and reduction of carbon dioxide utilising the

'assimilating power' and is localised in the stroma. This phase does not require light and hence it is referred to as the dark or the biosynthetic phase of photosynthesis.

Photochemical Phase (*Light Reaction*)

Some of the pioneering scientists who have contributed substantially to our understanding of the photochemical reactions are: R. Emerson, D. I. Arnon, E. Rabinowitch, L. M. N. Duysens, R. Hill, and F. Bendall.

When chlorophyll absorbs a photon of light, the added energy from this photon lifts an electron from the ground state (the low energy state) of the chlorophyll molecule to the excited state (the high energy state)

$$Chl + h\nu \longrightarrow Chl^{*} \qquad (4)$$

Where Chl represents chlorophyll in ground state, *hν*, the energy in a photon of light, and Chl^{*} the excited chlorophyll molecule.

This excitation of chlorophyll molecule results in the transfer of an electron from chlorophyll utlimately accomplishing the reduction of $NADPH_2$. The chlorophyll molecule which has lost an electron (Chl^{+}) during this process regains its electron from the water molecule through an electron transfer system and returns to its original ground state. During these electron transfers which occur in the presence of light, some of the energy released is conserved to form the energy-rich compound adenosine triphosphate from adenosine diphosphate (ADP) and inorganic phosphate (Pi). This process of energy conservation associated with photosynthetic electron transport is known as *photophosphorylation*. These processes are cooperative and involve two sets of photochemical reactions (Fig. 16.8) catalysed by pigment systems known as the *Photosystem I and Photosystem II*.

In photosystem I, the chlorophyll excited by light, transfers an electron which is ultimately involved in the reduction of NADP to $NADPH_2$. In photosystem II, the photo-excited chlorophyll transfers one electron which passes through a series of intermediate substances ultimately reducing the chlorophyll molecule of the photosystem I which is oxidised earlier. The photosystem II which loses its electrons, in turn regains them from water (Fig. 16.8). During this process of electron transfer from photosystem II to photosystem I, part of the energy released is utilised for the formation of ATP.

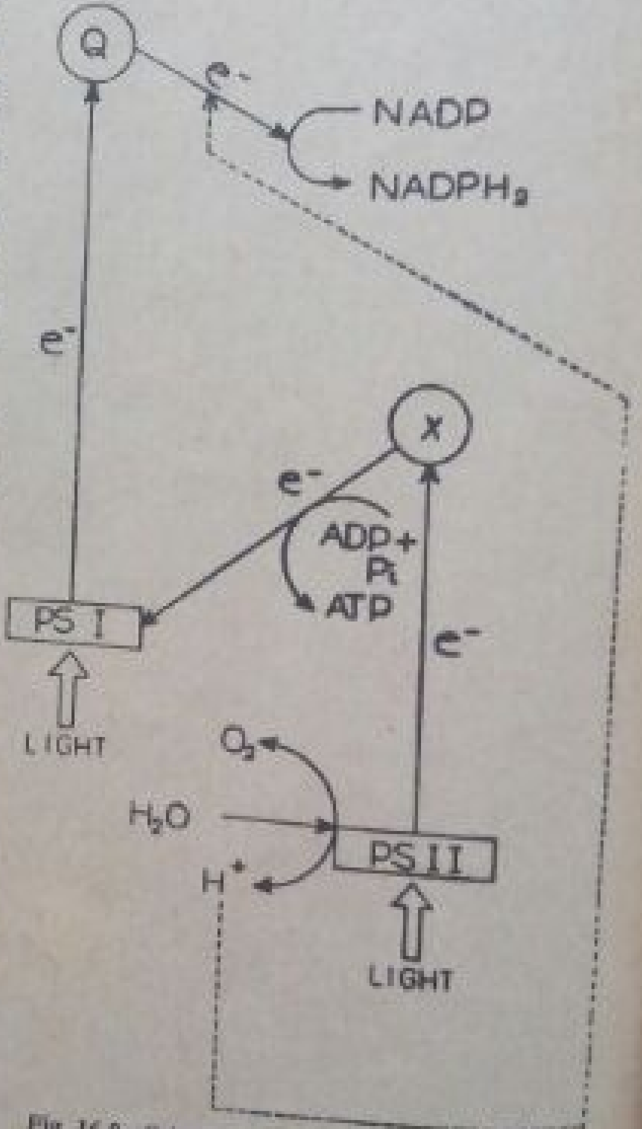


Fig. 16.8 Schematic representation showing two photochemical reactions in photosynthesis. PSI: Photosystem I; PSII: photosystem II. Q and X represent some intermediate substances.

...nthetic Phase (Dark Reaction)

The 'assimilating power', $NADPH_2$ and ATP generated in the photochemical reac... is utilised for the fixation and reduc... of CO_2. Light is not required for this process. The enzymes necessary for this process are present in the stroma phase of the chloroplast. The reaction sequence of this process was elucidated by Calvin, ...son and their colleagues.

The whole process of fixation and reduc... of carbon dioxide takes place by three major steps as shown in Fig. 16.9.

The first step is the carboxylation of a ...tose sugar, ribulose-1, 5 - diphosphate (RUDP), namely the addition of CO_2. This results in the formation of phosphoglyceric acid (PGA) a three-carbon molecule. Thus it can be seen that ribulose-1, 5- diphosphate is the CO_2 acceptor and PGA is the first stable product of the CO_2 fixation.

In the second step PGA is reduced to 3-phosphoglyceraldehyde utilising the ATP and $NADPH_2$ produced in the photochemical reactions. The 3-phosphoglyceraldehyde exists in equilibrium with its isomer, dihydroxyacetone phosphate and they are referred to collectively as triose phosphates. Part of the triose phosphate is polymerised to give rise to six-carbon (C_6) sugar.

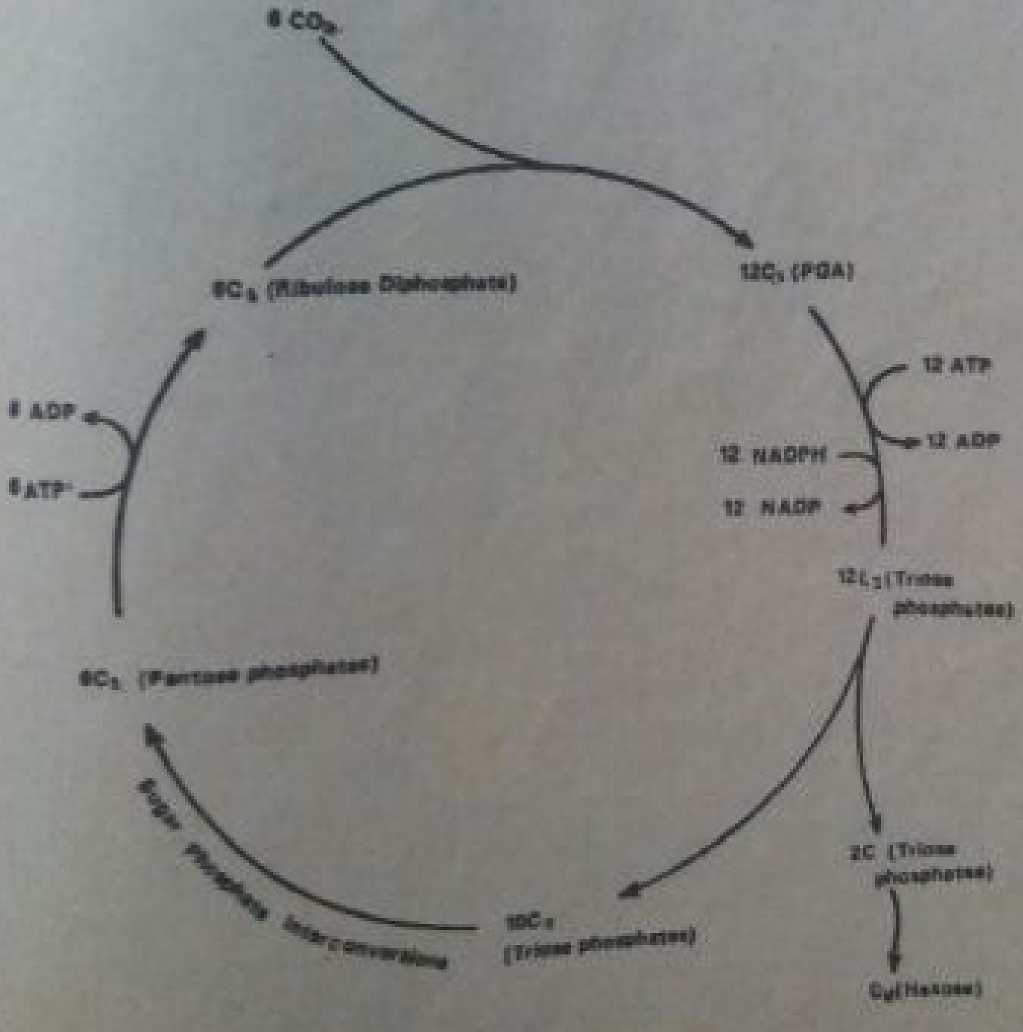


Fig. 16.9 Calvin cycle

In the third step, the triose phosphate undergoes a series of transformations ultimately resulting in the regeneration of the CO_2 acceptor molecule ribulose-1, 5-diphosphate utilising the ATP.

The whole process operates by the mediation of many enzymes in a cyclic manner producing carbohydrates (C_6 sugars) and regenerating ribulose-1, 5-diphosphate, the CO_2 acceptor. This cyclic process is known as the *Calvin cycle*.

C_4 Photosynthesis: Recently it was observed that in certain plants including sugarcane and maize, the first stable compounds formed from the initial carbon dioxide fixation are C_4 dicarboxylic acids, the malic and aspartic acids. During the primary carboxylation reactions in these plants, carbon dioxide combines with phosphoenol pyruvic acid (PEP) to form oxaloacetic acid which is then reduced to malic acid or aminated to aspartic acid. The enzyme PEP carboxylase is responsible for the carboxylation of PEP. The C_4 dicarboxylic acid thus formed transfers one carbon to ribulose diphosphate (which is part of the same cycle as Calvin had postulated), the remaining 3 carbon atoms appearing as pyruvic acid. Pyruvic acid is converted to PEP thus completing the cycle (Fig. 16.10). This process is called the C_4 Photosynthesis or the Hatch and Slack pathway and the plants are termed the C_4 plants as distinct from the C_3 or *Calvin type* plants based on the respective first products of carbon fixation. The C_4 plants will have both Hatch and Slack pathway and Calvin cycle linked together by a carbon transfer reaction.

Plants which exhibit C_4 Photosynthesis have a specialised anatomy in their leaves called the *Kranz anatomy* (Fig. 16.4). The vein of the leaf is surrounded by bundle sheath, the cells of which contain abundant chloroplasts. The mesophyll cells immediately adjacent to the bundle sheath also

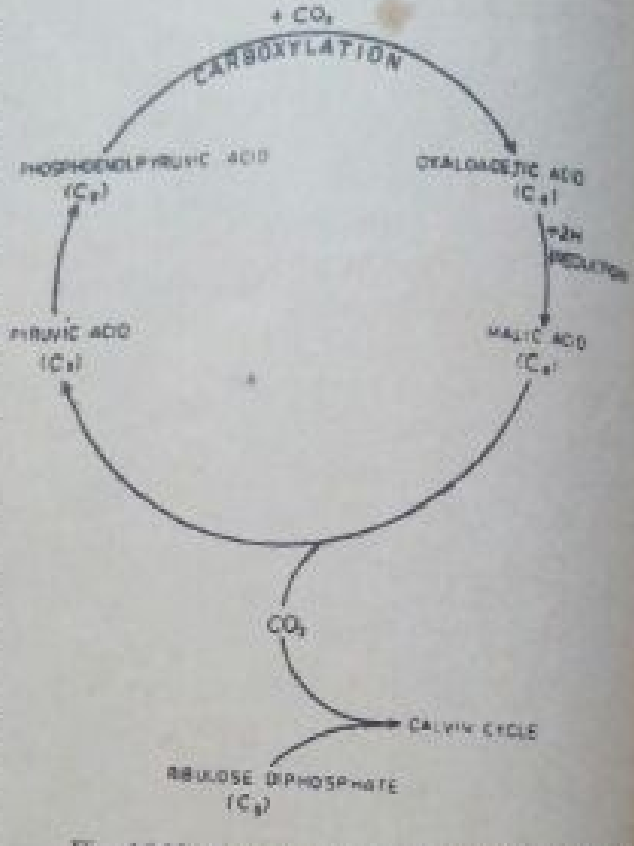


Fig. 16.10 Carbon dioxide fixation in C plants Hatch and Slack Pathway.

contain large number of the chloroplasts. The bundle sheath cells show predominantly the Calvin cycle metabolism and the mesophyll cells, the C_4 acid metabolism. Thus the C_4 plants differ from C_3 plants in having abundant PEP carboxylase in the mesophyll cells. According to Hatch and Slack the malic and/or aspartic acids that are formed in the mesophyll cells as a result of the initial carboxylation reaction are transported to bundle sheath cells where decarboxylation occurs and CO_2 released is refixed into PGA.

C_4 plants photosynthesize more efficiently than C_3 plants, C_4 photosynthesis occurs in several plants such as sugar cane, maize, *Euphorbia*, *Amaranthus*, *Portulaca*, and *Chenopodium*.

FACTORS AFFECTING PHOTOSYNTHESIS

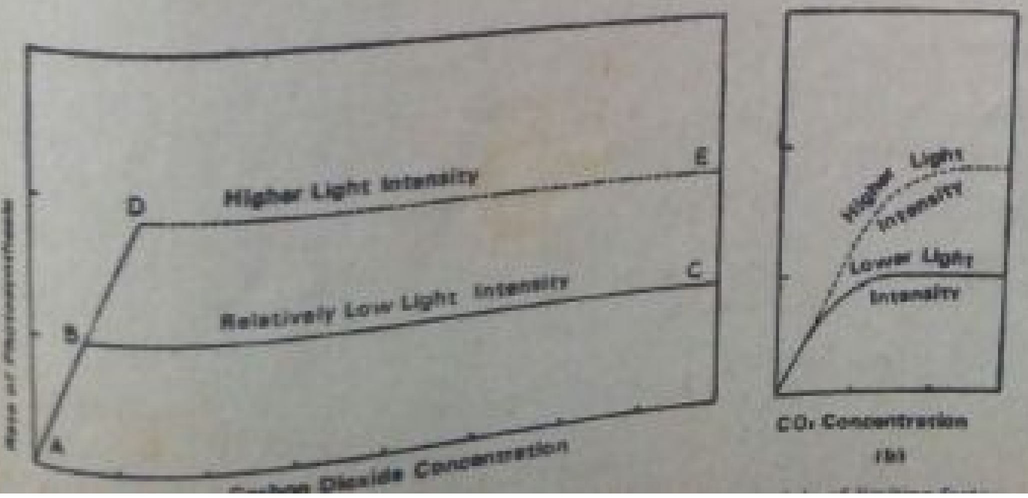
The rate of photosynthesis is controlled by a number of environ... and internal f...

onmental Variables

he important environmental variables ich control the rate of photosynthesis are ht intensity, carbon dioxide, temperature d availability of water. Each variable has inimum, optimum and maximum effects the rate of photosynthesis. Blackman has oposed the *Principle of Limiting Factors* explain the influence of these factors on e rate of photosynthesis. According to this nciple, when other factors are kept con- nt the factor under consideration (e.g., rbon dioxide) increases the rate of photo- thesis from a minimum to an optimum, ablishing a plateau. Any further increase that factor (CO_2) does not affect the rate. e reason is that at this point some other tor becomes limiting. If any one of the er factors which is kept constant (say, ht) is increased, the photosynthetic rate reases again reaching an optimum where ain another factor becomes limiting g. 16.11a). The curve resulting from a ting factor is not an abrupt transition to plateau state as proposed by Blackman t a gradual transitional movement to a sition approximately parallel to the abs- sa (Fig. 16.11b).

Light: The rate of photosynthesis is affected by intensity and quality of light. At low light intensities, the rate of photosynthesis is low. With increase in light intensity, carbon dioxide fixation also increases until some other factors become limiting. This may also result in a point of saturation at which time the rate of photosynthesis remains stationary. Based on the amount of light required to saturate the photosynthetic rate, plants may be classified into two categories, the *sun* and *shade* plants. Sun plants require relatively high light intensity to saturate their photosynthetic rates. Shade plants reach saturation at low light intensities. Most of the crop plants, for example, maize, are sun plants and they are considered to be more effective in photosynthetic rate. *Oxalis* is an example of a shade plant. In such cases extremely high light intensities have an inhibitory effect on photosynthesis due to a process known as *photo-oxidation*. During this process abnormal photochemical reactions occur oxidising most of the cellular components including chlorophyll.

The quality of light also influences the rate of photosynthesis. For example, plants



growing under a thick forest canopy are supplied with proportionately more of green wave lengths than blue and red which are absorbed by the leaves above. As a result, the rate of photosynthesis of the herbs, shrubs and smaller trees growing under these plants will be affected since green light is inert for photosynthesis.

Carbon dioxide: The concentration of CO_2 in the air is 0.03 per cent by volume. Though small in amount, it plays an important role in the biological world.

In land plants, the bulk of carbon dioxide enters the leaf through the stomatal apertures. In the hydrophytes the entrance of carbon dioxide, bicarbonates or carbonates, is directly through the epidermis.

There is good correlation between the concentration of carbon dioxide and the rate of photosynthesis. With an increase in the concentration of carbon dioxide there is an increase in the rate of photosynthesis provided the quality of light itself is not a limiting factor. Relatively high concentrations of carbon dioxide cause a decline in the rate of photosynthesis.

Temperature: The effect of temperature on the rate of photosynthesis varies from plant to plant. Its effect also depends upon the intensity of light and concentration of carbon dioxide. Some of the bacteria and blue-green algae carry out photosynthesis at temperatures as high as 70°C, while many of the conifers carry out photosynthesis even at −6°C. For most of the plants the optimal temperature for photosynthesis lies between 20° and 35°C. Temperature may not have any effect on the photochemical part of photosynthesis but has a profound effect on the enzyme controlled reactions of the Calvin cycle.

Availability of water: Less than 1.0 per cent of the water absorbed by a land plant is utilised for photosynthesis. Water supplies the electrons required for the carbon dioxide reduction and it also plays a role in the opening and closing of the stomata. A decrease in the water content of the leaves reduces the rate of photosynthesis. The reduction in the photosynthetic rate is caused by the closing of the stomata resulting in a decrease of carbon dioxide absorption and also due to the dehydration of protoplasm which affects the enzymes involved in photosynthesis.

Internal Factors

The principal internal factors that control the rate of photosynthesis are age of leaf, chlorophyll content and the anatomy of the leaf.

Age of leaf: The leaf originates at the short apex and develops gradually into a mature leaf. As the leaf develops, the rate of photosynthesis increases gradually reaching a maximum around its maturity followed by a decline with age.

Content of chlorophyll: It may be expected that the rate of photosynthesis increases with an increase in content of chlorophyll; however, it has been shown that there is no relationship between the two in leaves of vascular plants. For example, the sun plants which contain less chlorophyll in their leaves than the shade plants show a rapid rate of photosynthesis in bright light.

Anatomy of leaf: The rate of photosynthesis in a leaf is also partly conditioned by its anatomy. The rate of photosynthesis may be influenced by the number, structure, and distribution of the stomata, the size and distribution of intercellular spaces the relative proportions and distribution of palisade and spongy tissues, the thickness of the cuticular layer and the size and distribution of the vascular system. Leaves with a specialised anatomy known as the 'Kranz anatomy' (as already described), exhibit division of labour between the chloroplasts of the two cell types (bundle sheath and mesophyll cells) and are very efficient in photosynthesis (see Fig. 16. 4).

Transpiration

Transpiration is the loss of water in the form of vapour from the plants. Most of the transpiration takes place from the leaf. Water evaporates from the moist cell walls exposed to the leaf's internal atmosphere and pass out through the stomata as vapour. This large internal moist surface of cells and the stomata of the leaf are actually necessary to facilitate the absorption of carbon dioxide and oxygen.

Plants retain only a small portion of water that is absorbed by the roots for its physiological functions while the rest is lost by transpiration. Transpiration may occur through the cuticle (*cuticular transpiration*) or the stomata (*stomatal transpiration*). The principal route of transpiration is through the stomata.

MECHANISM OF STOMATAL ACTION

The stomata are small apertures bounded by two guard cells that occur in the epidermis of the leaves (Fig. 16.2) and on other aerial parts of the plant. The size, structure and distribution of the stomata vary.

The stoma is 'the turgor-operated-valve' of the leaf. The opening and closing of the stomata are controlled by the size and shape of the guard cells resulting from changes in their water content. In dicotyledons, the walls of the guard cells are unevenly thickened (Fig. 16.12a). The inner walls of the guard cells bordering the aperture are thicker than the outer wall. With increase in the turgor of the guard cells, the outer walls becomes more convex drawing the inner walls apart and opening the pore. When the turgor of the guard cells decreases the inner walls return to their original position resulting in the closure of the pore (Fig. 16.12a). In monocotyledons, the guard cells are dumb-bell shaped. The inflated part of the cells have thin walls while the intervening walls have thick walls (Fig. 16.12b). When the guard cells become turgid, the regions with thin walls bulge drawing the thick walls apart and opening the pore.

While the opening and closing of the stomata depends on the increase or decrease of the turgor of the guard cells, the mechanisms which control the movement of water into the guard cells are not clearly understood. The movement is affected by a variety of external stimuli, namely, light, concentration of carbon dioxide and water.

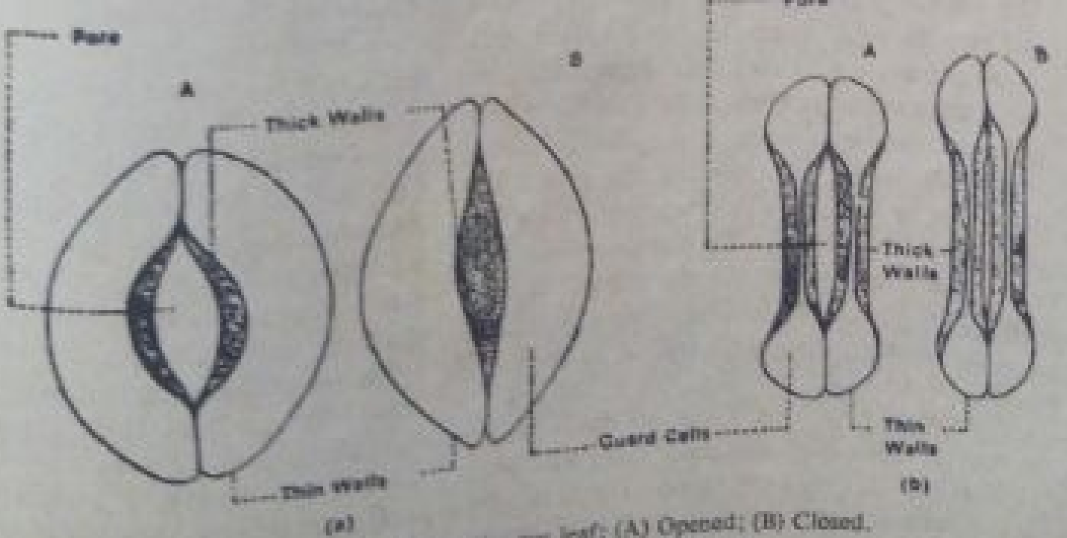


Fig. 16.12 (a) Stoma of a dicotyledonous leaf: (A) Opened; (B) Closed.
(b) Stoma of a grass leaf: (A) Opened; (B) Closed.

In mesophytic leaves, the stomata usually tend to open during day and close during night. In succulent plants (e.g., Cacti and *Bryophyllum*) the stomata commonly open at night and close by day.

One of the earliest hypotheses to account for the opening of the stomata is increase in sugar content and the concurrent increase in the content of solute following photosynthesis in the guard cells. Water then enters into the guard cells resulting in increased turgor. This explanation is not adequate since the photosynthetic rate is too slow to account for the changes in turgor to cause the cells to open. This hypothesis cannot also explain the opening of the stomata in the dark by some plants (succulents).

Another theory formulated by Sayre in 1923 and studied extensively by Scarth (1932) is based on starch content. When the guard cells contain starch, the stomata are closed and when they are starch free the stomata are open. According to this theory carbon dioxide accumulated in the guard cells, in the dark, reduces the pH (that is an increased acidity due to formation of carbonic acid) of the cytoplasm. In the light, carbon dioxide is utilised in photosynthesis thereby raising the pH. A rise in pH stimulates the enzyme amylase which hydrolyses starch to sugars. The production of sugars reduces the water potential of the cells thereby directing the water to move into the guard cells. This theory, however, explains only the opening of the stomata in light. It fails to explain the opening of the stomata in the dark by succulent plants where it appears to be caused by the accumulation of organic acids synthesised from carbon dioxide in the dark (CO_2 fixation in the dark is a special feature of succulent plants).

Levitt (1967) proposed a logical explanation for the mechanism of stomatal action by modifying the old theories. The starch produced by photosynthesis in light is converted to organic acids resulting in low CO_2 concentration. Potassium ions play a significant role in the accumulation of organic acids. This increase in organic acids in the guard cells increases the concentration of cell sap followed by subsequent absorption of water. Thus, an increased turgor of the guard cells results causing the opening of the stomata. In the dark, photosynthesis ceases accompanied by an increase in concentration of CO_2. The organic acids are converted to starch decreasing the concentration of cell sap. This results in the movement of water out of the guard cells, a decrease in their turgor and the closure of the stomata (Fig. 16.13). This concept explains to a certain extent the opening and closing of the stomata both in succulents and non-succulents.

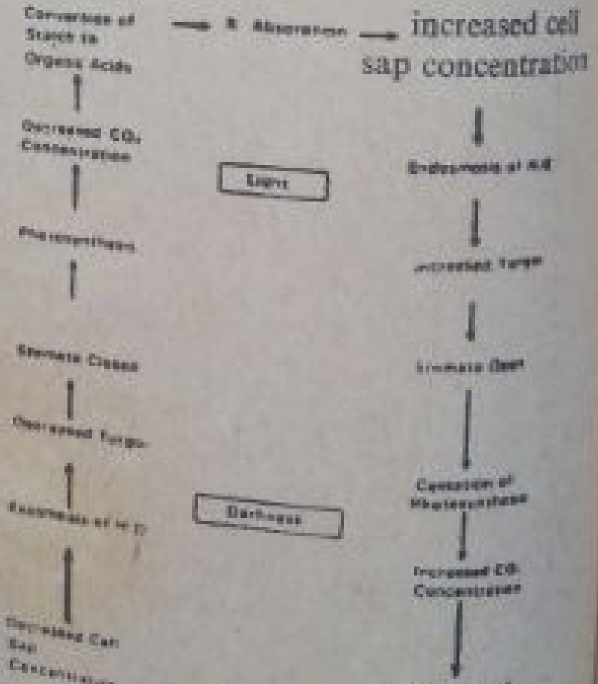


Fig. 16.13 Opening and closing of the stomata

...CTORS AFFECTING TRANSPIRATION

The rate of transpiration may be affected ...y several factors including the environmen...l and plant factors.

...vironmental Variables

The important variables that affect the ...e of transpiration are light, humidity of ...r, temperature, wind and availability of soil ...ater. In nature, the transpiration rate of a ...lant is influenced by several of these vari...bles at any one time.

Light: In most plants light influences the ...pening of the stomata and is, therefore, an ...portant environmental variable.

Humidity of air: The diffusion and eva...oration of water from the internal atmos...phere of the leaf to the outside atmosphere ...epends on vapour pressure of the outside ...tmosphere. Usually the internal atmosphere ...f the leaf is nearly saturated while the ...tside atmosphere is relatively unsaturated. ...hus, a diffusion pressure gradient exists ...etween the internal atmosphere of the leaf ...d the outside atmosphere and hence water ...apour diffuses from the leaf with high ...apour pressure to the outside atmosphere ...ith low vapour pressure through the ...omata. Other factors being equal, the rate ...f transpiration depends upon the vapour ...essure in the outside atmosphere. High ...apour pressure in the outside atmosphere ...sults in a lowered rate of transpiration and ...low vapour pressure outside, on the other ...and, increases the rate of transpiration.

Temperature: A rise in temperature within ...certain physiological range, generally ...creases the rate of transpiration. This is ...e to the effect of temperature on the ...omatal opening and the gradient of vapour ...essure. The stomata close at very low ...mperatures as well as at very high tem...peratures.

Wind: The air near the transpiring leaf ...concentrated with water vapour diffused ...m the leaf. This decreases the vapour pressure gradient thereby decreasing the rate of transpiration. However, wind removes the concentrated vapour near the leaf surface, and increases transpiration. Excessive wind velocities also decrease transpiration due to a closure of the stomata in response to the mechanical effects of wind on the leaves and to a loss of water from the guard cells by drying. Wind also plays a significant role in cooling the leaf followed by a decrease in the rate of transpiration.

Availability of water: Availability of water in the soil is an important factor which affects transpiration. Transpiration decreases when sufficient water is not available to the plant from the soil due to decrease in movement of water. Water is lost from the guard cells resulting in the closure of stomata and consequent wilting of the plant. Wilting occurs when loss of water by transpiration exceeds the rate of uptake of water.

Plant Factors

Among the plant factors that control the rate of transpiration are, the root-shoot ratio, leaf area and leaf anatomy.

Root-shoot ratio: The rate of transpiration depends upon the efficiency of the absorbing system (roots) and the evaporating system (leaves). The rate of transpiration increases with an increase in root-shoot ratio.

Leaf area: Increase in leaf area, is generally expected to be associated with an increase in the rate of transpiration. However, this is not always the case. There is no relation between leaf area and water loss. In large plants, the transpiration rate may be higher per plant though on unit area basis, the rate of transpiration is more in the smaller plants than larger ones.

Leaf structure: Plants that grow in dry habitats (xerophytic plants) show many structural modifications, specially in leaves, to reduce transpiration. The leaves are reduced in size and have thick cuticle, sunken

stomata, a covering of dead epidermal hairs, thick cell walls, well developed palisade parenchyma, etc. It can be observed that under identical conditions, if two detached xerophytic and mesophytic leaves are allowed to dry, the mesophytic leaf wilts earlier than the xerophytic leaf.

MEASUREMENT OF TRANSPIRATION

Several methods are used for measurement of transpiration based on determination of the (1) water absorbed, (2) water vapour transpired by a plant.

Method Based on Weighing of Plants

The amount of water lost by transpiration can be determined by weighing a potted plant at the beginning and at the end of a prescribed period of time. The loss in weight is taken as the water transpired. The soil surface and the pot are sealed with aluminium foil to prevent water evaporation from areas other than the plant. Though photosynthesis and respiration of the plant affect weight, the loss may be considered insignificant compared to the water lost by transpiration. This method is suitable for determining the rate of transpiration by small plants.

Colour Indicator Method

In this method, pieces of filter paper soaked in 3 or 5 per cent cobalt chloride solution, dried in an oven and stored in a desiccator are used. The filter paper appears pink when wet and blue when dry. At the time of measurement, the filter paper (blue) is placed on the leaf surface held in place between two glass slides and tied tightly with thread. The time taken for change in colour from blue to pink following absorption of moisture from transpiration is a measure of the amount of water lost by the portion of the leaf covered by the paper.

The indicator method may not give actual rate of transpiration because by placing the paper the surface of the leaf is cut off from light and movement of air.

Potometer Method

This method is based on the assumption that water transpired is equal to water absorbed. The apparatus consists of a vessel filled with water in which a cut stem or a plant is placed and sealed. The glass vessel is connected to a water reservoir and a capillary tube (Fig. 16.14). A bubble is introduced into the capillary tube. The movement of the bubble through the graduated capillary tube is considered a measure of the rate of transpiration. This method measures only water absorption rather than transpiration because under certain conditions the water absorbed is not equal to transpiration.

Method of Collecting and Weighing Water Vapour Lost in Transpiration

In this method a plant is enclosed in a glass container. Air of known moisture content is allowed to flow into the container and out through tubes containing pre-weighed water absorbing material, e.g., calcium chloride. After a prescribed period, the calcium chloride is weighed. A control set is also maintained with the same volume of air drawn through the apparatus without the plant. The amount of water transpired is

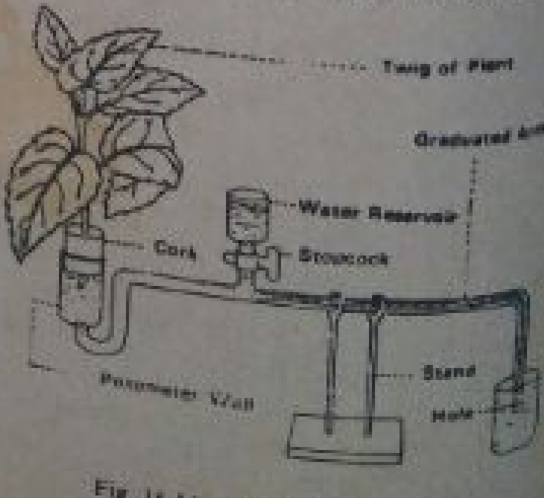


Fig. 16.14 Ganong's potometer

...rmined from the difference between the ...ht of the two calcium chloride samples. This method is also not perfect since the ...t is placed in a closed container under ...rmal conditions of light intensity ...perature and humidity which are not ...ural.

...IFICANCE OF TRANSPIRATION

Transpiration maintains an optimum tur-...ity of the cells. It also maintains the ...ement of water and minerals absorbed ... the roots to the other parts of the plant ...ugh the xylem elements. It also acts as ... mechanism which cools the leaf and ...vents damage at high temperatures.

...-Transpirants

I... dry seasons, crop plants may wilt and ...ult in poor yields due to lack of sufficient ...ter to replace the water lost through ...spiration. The rate of transpiration can ... red... by spraying such crop plants ...th che...icals known as *anti-transpirants*. A ...uction in the rate of transpiration can be ...ieved by these substances in two ways ... by using metabolic inhibitors which ...se the stomatal opening (e.g., phenyl ...curic acetate, abbreviated as PMA and ...scisic acid abbreviated as ABA), (2) by ...ing film forming substances, which cover ... leaf surface reducing the transpiration ...e (e.g., silicon emulsions). These are still ... the experimental stage only.

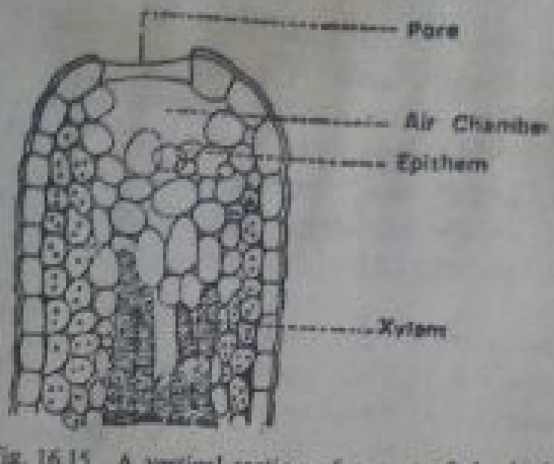


Fig. 16.15 A vertical section of a part of the leaf showing hydathode.

Guttation

The loss of water in the form of liquid, as droplets along the margins of the leaves (Fig. 16.15) through specialised structures called *hydathodes* is known as *guttation*. Hydathodes are present at the tip of the veins of leaves. A hydathode consists of a pore in the epidermis, followed by large intercellular spaces, loosely arranged parenchyma and blindly ending xylem elements. Guttation is usually found in herbaceous plants growing in moist, warm soil and under humid conditions. When the absoprtion of water exceeds that of transpiration, hydrostatic pressure is built up in the xylem ducts as a result of which water is pushed up the xylem ducts and out through the hydathodes. The water of guttation contains several dissolved inorganic and also organic substances.

EXERCISES

What is the law of limiting factors?

How do you prove that the source of oxygen in photosynthesis is the water molecule and not carbon dioxide?

What is 'Kranz anatomy'? Comment on the rate of photosynthesis in plants having this type of anatomy.

What is the Hill reaction?

5. What is photophosphorylation?
6. What are anti-transpirants?
7. Describe the structure of a dicotyledonous leaf.
8. Describe the structure of a monocotyledonous leaf.
9. Describe briefly the mechanism of photosynthesis.
10. Describe briefly the effect of various factors on the process of photosynthesis.
11. Describe the process of transpiration? How do you measure it?
12. Give a brief account of mechanism of stomatal movement.

CHAPTER 17

Respiration

NERGY is necessary for the growth and aintenance of life and the growth of all rganisms. The latter ultimately depend pon the products of photosynthesis as eir energy source. The process of release of ergy by the step-wise oxidation of organic bstances (substrates) constitutes *respira-on*. Carbohydrates form the principal bstrates of respiration. Fats are used in me special cases, as in a few germinating eds. Proteins are rarely used.

he oxidation of substrates during respi-tion involves a series of enzymatic reac-ons and electron transfers. If oxygen is t involved in the degradation of carbo-drates, and products like CO_2 and ethyl ohol or lactic acid are formed, the process known as *anaerobic respiration*. The an-obic breakdown of glucose can be broadly presented as:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

When oxygen acts as the ultimate electron ptor in respiration and it is reduced to water, the process is described as *aerobic respiration*. The complete oxidation of glu-cose molecule can be broadly represented as;

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O \quad (2)$$

Glycolysis

Glycolysis is a process in which one mole-cule of glucose (a 6-carbon compound) is converted to two molecules of pyruvic acid (a 3-carbon compound) through a series of reactions involving several intermediate sub-stances as shown in figure 17.1. Glycolysis is also known as the Embden - Meyerhof - Parnas (EMP) pathway. All the glycolytic reactions take place in the cytoplasm. The conversion of glucose to pyruvic acid through glycolysis is common to both *anaerobic* and *aerobic* respirations.

During respiration when glucose is sub-jected to glycolysis, it is first converted into glucose - 6 - phosphate This reaction requires

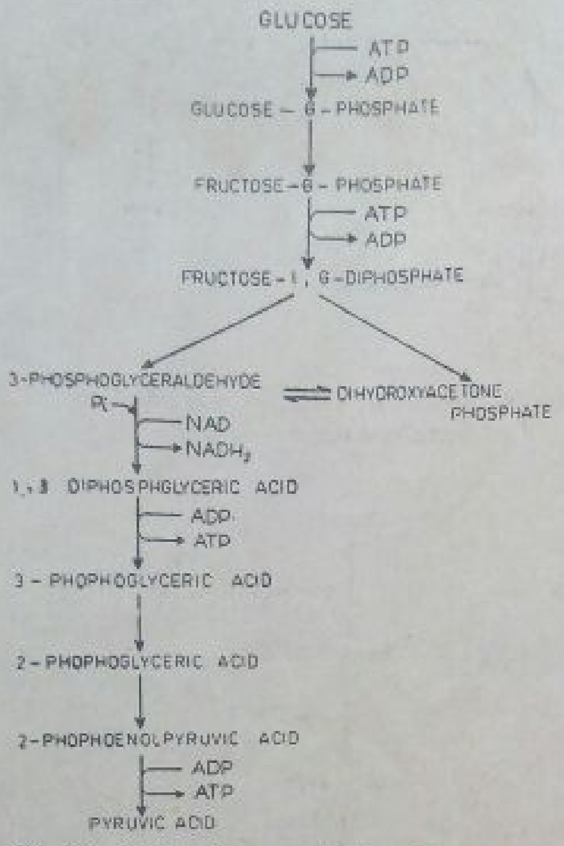


Fig. 17.1 Schematic representation of glycolysis.

one ATP molecule. In the next reaction glucose-6-phosphate is transformed into fructose-6-phosphate. The fructose-6-phosphate thus formed is further phosphorylated by ATP to form fructose-1,6-diphosphate. Thus, two molecules of ATP are utilised for the conversion of glucose to fructose-1, 6-diphosphate.

Fructose-1, 6-diphosphate (a 6-carbon diphosphorylated sugar) splits into two 3-carbon phosphorylated compounds (triose phosphates) known as 3-phosphoglyceraldehyde and dihydroxyacetone phosphate. These triose phosphates are interconvertible and occur in equal proportions. Only 3-phosphoglyceraldehyde is further oxidised in glycolysis. Thus, as 3-phosphoglyceraldehyde is utilised in the process, it is regenerated from dihydroxyacetone phosphate resulting in the utilisation of both the trioses.

The 3-phosphoglyceraldehyde that is formed is converted to 1, 3-diphosphoglyceric acid in the presence of inorganic phosphate (P_i) and NAD. During this process NAD is converted to $NADH_2$. In this reaction the phosphate that is added to the molecule, is utilised for ATP synthesis in the next reaction and the $NADH_2$ generated participates in the electron transport, which will be discussed later.

In the next reaction 1, 3-diphosphoglyceric acid is converted to 3-phosphoglyceric acid. During this process phosphate group that is liberated is utilised for the formation of ATP from ADP. In the reaction that follows, 3-phosphoglyceric acid is converted to 2-phosphoglyceric acid. Then the 2-phosphoglyceric acid formed loses one molecule of water resulting in the formation of 2-phosphoenolpyruvic acid. Then in the presence of ADP, 2-phosphoenolpyruvic acid is converted to pyruvic acid. During this process the phosphate group of 2-phosphoenolpyruvic acid is transferred to ADP to form ATP.

Each step in the above sequence of reactions is controlled by an enzyme.

With the formation of pyruvic acid the glycolytic sequence is completed. In the process of glycolysis 2 ATP molecules are consumed and 4 ATP molecules per glucose (2 ATP per triose) are synthesized. Thus the net production of ATP molecules for every glucose molecule is 2 (that is 4 ATP molecules synthesized minus 2 ATP molecules consumed). Glycolysis also results in the formation of 2 $NADH_2$ per molecule of glucose. What happens to the $NADH_2$ formed depend on whether respiration follows the anaerobic or the aerobic pathway. The pyruvic acid formed may undergo complete aerobic oxidation to CO_2 and H_2O or it may be anaerobically broken down to CO_2 and alcohol or lactic acid.

he absence of oxygen, plants continue
duce carbon dioxide at least for some
and this proves that plants can respire
obically. It is curious that some micro-
isms exist totally in anaerobic condi-
The term anaerobic respiration is
ly applied with reference to higher plants
erged roots of paddy plants) and the
fermentation is used for the anaerobic
down of sugars, proteins and other
ances by bacteria and yeast. The end
ucts of fermentation are carbon dioxide
other organic substances such as ethyl
hol and lactic acid.

alcoholic fermentation the removal of
on dioxide (decarboxylation) from pyru-
cid results in the formation of acetalde-
, which in turn is reduced to ethyl alcohol
$NADH_2$ formed earlier (Fig. 17.2). In
acid fermentation, pyruvic acid is
tly reduced by means of $NADH_2$
. 17.2) to lactic acid.
ly 2 ATP molecules are produced during
robic glycolysis.

IC RESPIRATION

robic respiration is most common in
r plants (also animals). Pyruvic acid
rated in glycolysis is completely oxidised
gh a step-wise cyclic process known as
acid cycle, *tricarboxylic acid cycle*
cycle) or *Krebs cycle*. An outline of
c respiration is presented in Fig. 17.3.
details of the citric acid cycle were
ed and explained by Sir Hans Krebs in
and have been, therefore, named after
In contrast to glycolysis which occurs
cytoplasm the reactions of the citric
cycle take place exclusively in the
hondria (Fig. 17.4).

Structure of Mitochondrion

mitochondria are either oval or saus-
aped organelles and measure about 3μ
in length and 0.5 μ in breadth. The detailed
structure of a mitochondrion can be under-

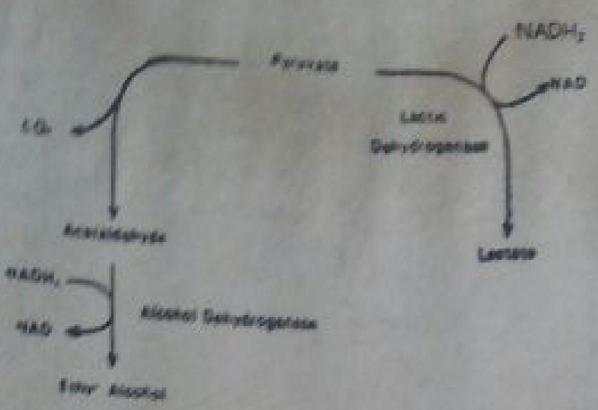


Fig. 17.2 Schematic representation of alcoholic and lactic acid fermentation.

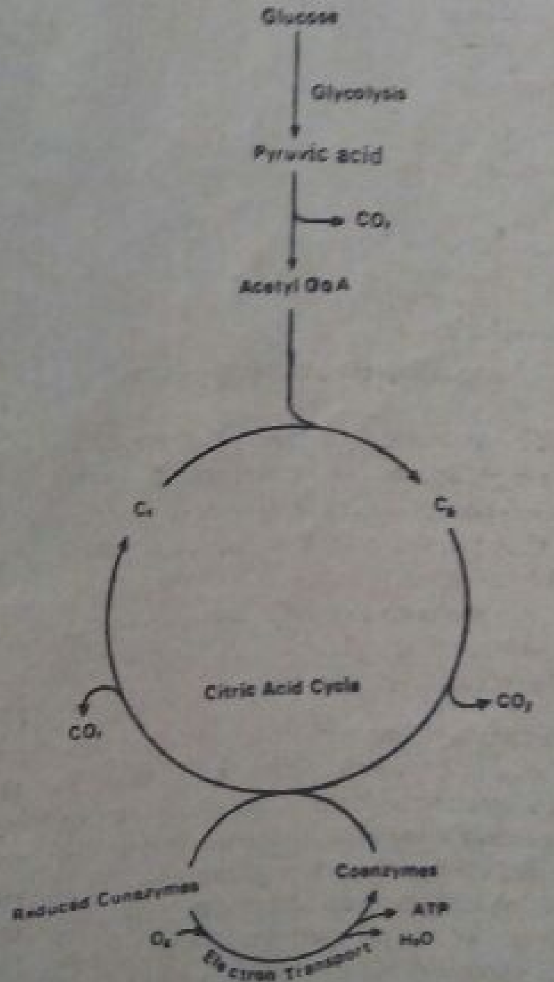


Fig. 17.3 An overall view of aerobic respiration.

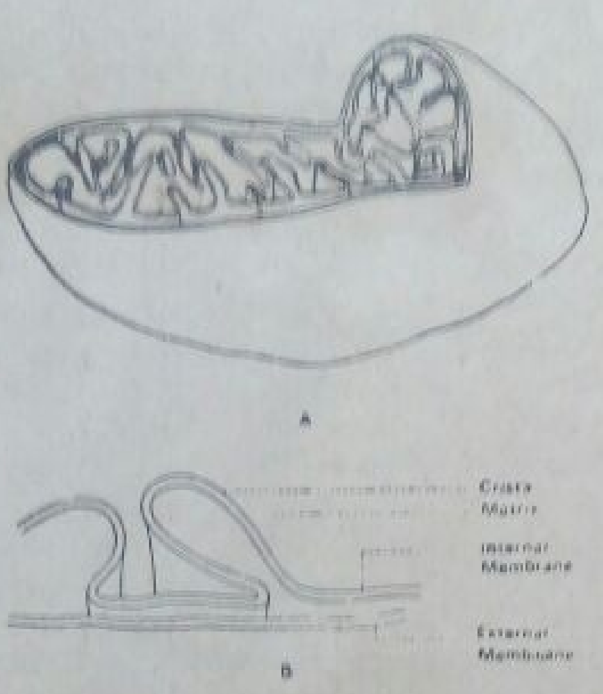


Fig. 17.4 Mitochondrion structure: (A) Partly cut to show three-dimensional structure; (B) Cristae shown separately.

stood by studying its electron micrograph. Each mitochondrion has two membranes—a smooth outer membrane and an inner membrane showing numerous folds that project into the matrix. These foldings are called the *cristae* (crista is singular). The membranes are made up of proteins and lipids. Numerous stalked bodies are present on the cristae with which the enzymes necessary for the oxidation of pyruvate are associated. Some other enzymes of mitochondria are located in the matrix. Mitochondria also store a large amount of ATP.

Citric acid Cycle

Pyruvic acid, the product of glycolysis, enters mitochondria where it is subjected to reactions of the Citric Acid Cycle (Fig. 17.5). In this cycle each molecule of pyruvic acid is broken down to carbon dioxide and water by passing through a series of reactions. Again, each step in this cycle of reactions is controlled by an enzyme.

The initial reaction involves the removal of CO_2 from pyruvic acid and combination of the resulting 2-carbon unit with the sulph containing compound, coenzyme A (abb viated as CoA) to form Acetyl CoA (Acti acetate). During this process the hydrog released is accepted by NAD to fo $NADH_2$. Thus, this reaction is characteris by both decarboxylation and dehydrogen tion.

Acetyl CoA then condenses with a carbon acid, oxaloacetic acid to form 6-carbon molecule, the citric acid. The citr acid exists in equilibrium with *Cisaconit acid* and *isocitric acid* which are interconver table.

In the reaction that follows isocitric aci is dehydrogenated to form oxalosuccinic aci and the hydrogen liberated during thi process is accepted by NAD. Oxalosuccini acid is a labile substance and is decarboxyla ted to α-ketoglutaric acid, a 5-carbon mole cule. Here we can see that another carbo atom which belongs to original pyruvic aci is lost as CO_2.

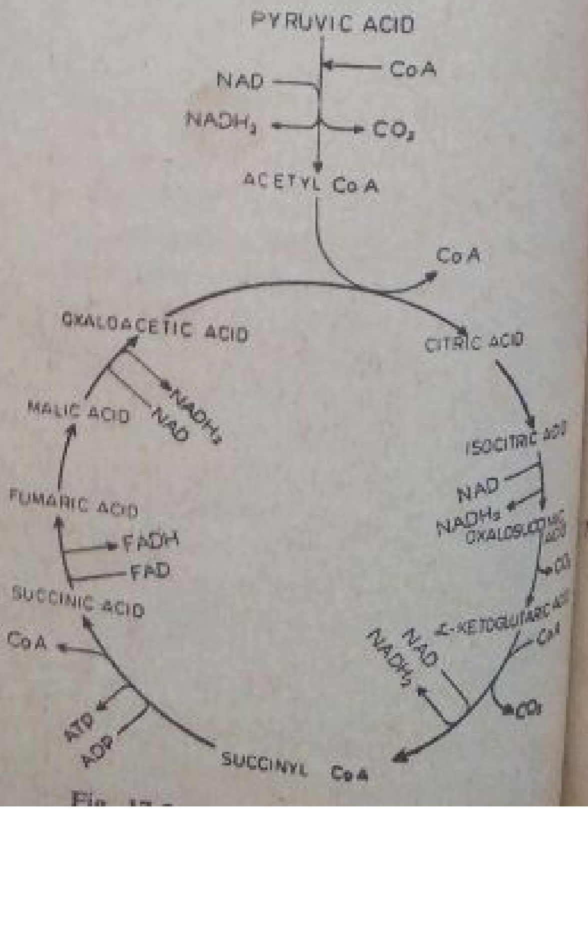


Fig. 17.

...quently, α-ketoglutaric acid is trans-
...d to a 4-carbon molecule, succinyl
...e A. This reaction involves coenzyme
...d NAD, the products being CO_2,
...H_2 in addition to succinyl CoA. With
...ction all the carbon atoms that entered
...ric acid cycle as pyruvic acid are
...d as CO_2.

...he reaction that follows succinyl CoA
...to succinic acid and CoA. This reaction
...terest in that ATP is formed directly
...g ADP and inorganic phosphate.

...the next reaction, succinic acid is
...d to form fumaric acid. The hydrogen
...s liberated during this reaction is
...ed by FAD (flavin adenine dinucleo-
...and not by NAD.

...the reaction that follows water is added
...fumaric acid and malic acid is formed.
...e next reaction malic acid is oxidised
...loacetic acid and in this reaction NAD
...as the hydrogen acceptor. The oxalo-
...acid so generated is now ready to
...e with the acetyl CoA, derived from
...c acid, thereby enabling the cycle to
...e continuously. Most of the reactions
...ed in this cycle are reversible.

..., by completing one cycle, three
...atoms of each pyruvic acid will be
...d as three carbon dioxide molecules,
...formation of one ATP, one $FADH_2$
...r $NADH_2$ molecules.

Electron Transport

The reduced coenzymes ($NADH_2$ and $FADH_2$) are oxidised by a process known as electron transport.

The oxidation of $NADH_2$ may be summarised as:

$$NADH_2 + \frac{1}{2}O_2 \longrightarrow NAD + H_2O \quad \ldots\ldots\ldots (3)$$

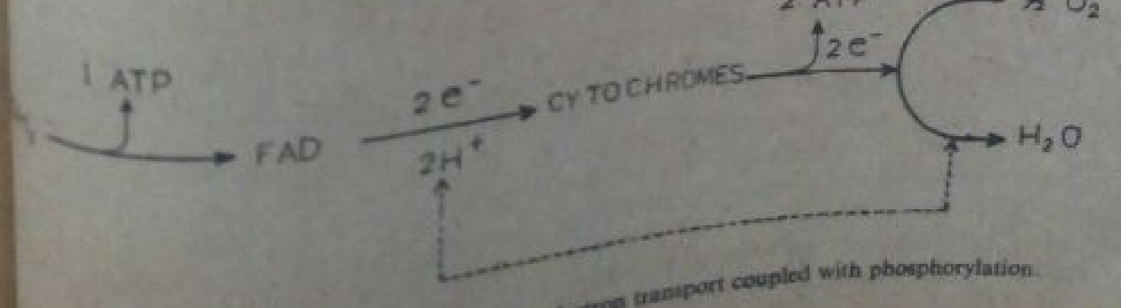
Actually the reaction (3) is not so simple, as the reduced coenzyme cannot directly combine with oxygen to form water. During the oxidation of the reduced coenzyme, the electrons that are released pass through various intermediate substances like the iron-containing proteins, the cytochromes. The electrons finally react with oxygen which gets reduced to water. The protons (H^+) needed for this purpose can be obtained as shown in the schematic representation of electron transport (Fig. 17.6).

The energy that is released during this electron transfer is utilised for the formation of ATP. The synthesis of ATP during aerobic respiration is termed *oxidative phosphorylation* as distinct from photophosphorylation of photosynthesis. Thus, electron transport is coupled to ATP formation.

ATP is the energy 'currency' of the cells. It is utilized in various life processes of the cells whenever needed, for synthesis, maintenance and growth.

Pentose Pathway

Although the major pathway for aerobic respiration of glucose is through glycolysis



...tion of electron transport coupled with phosphorylation.

and citric acid cycle, sometimes glucose passes through an alternative pathway known as *pentose phosphate pathway* (PPP), *Hexose monophosphate shunt* or *Warburg—Dickons cycle* which requires the presence of oxygen.

In this pathway, glucose-6-phosphate (a 6-carbon molecule) which arises from the initial reactions of glycolysis or directly from the photosynthetic reactions is oxidised to 6-phosphogluconic acid. During this process the coenzyme NADP (instead of NAD) acts as hydrogen acceptor. Then 6-phosphogluconic acid undergoes both dehydrogenation and decaroxylation resulting in the production of ribulose-5-phosphate, one carbon dioxide molecule and $NADPH_2$. In this pathway the production of CO_2 takes place at an earlier stage than in citric acid cycle. In the subsequent reactions ribulose-5-phosphate undergoes several changes involving various enzymes finally resulting in the formation of glucose-6-phosphate, thus operating the cycle continuously. The reactions of this cycle take place in the cytoplasm.

The PPP is of significance because it acts as a mechanism for glucose breakdown and several of the intermediates of this cycle are utilised in the synthesis of important compounds in the cell.

Respiratory Quotient

The ratio between the amount of CO_2 evolved to the amount of O_2 absorbed is expressed as respiratory quotient (RQ).

$$RQ = \frac{CO_2}{O_2}$$

From a study of this ratio it is possible to find out the nature of the substrate that is oxidised during respiration. Thus complete oxidation of a carbohydrate gives an RQ of 1.0 since the number of molecules of CO_2 evolved and the molecules of O_2 absorbed are the same. When fats act as substrates, the RQ value is around 0.7. Fats have less number of oxygen atoms in comparison to the number of carbon atoms in the molecules. Hence they require more oxygen for ox[idation] than carbohydrates which have gener[ally] an equal number of carbon and oxy[gen] atoms. The complete oxidation of prot[eins] gives an RQ value of about 0.9.

Factors Affecting Respiration

Several factors, both environmental [and] internal, affect the rate of respiration. T[he] study of these factors not only provides information regarding the nature of respi[ra]tion but also gives us clues for stori[ng] fruits, seeds, vegetables and foods in gener[al].

ENVIRONMENTAL VARIABLES

Temperature, oxygen, carbon dioxide, lig[ht] and inhibitors are some of the environment[al] variables that affect the rate of respiration.

Temperature: As with all chemical reac[tions], temperature affects respiration. Th[e] effect of temperature on respiration is mostl[y] based on its effects on enzymes. As th[e] temperature approaches 0 °C, we can observ[e] at reduction in the rate of respiration. As the temperature increases, the rate of respiration also increases, until temperatures which are destructive to enzymes are reached. Usually the maximum rate of respiration can be observed between 35° to 40 °C. But at temperatures above 30 °C the 'time factor' comes into operation. For example, in pea seedlings, it was observed that there is an initial rise in the rate of respiration from 0° to 40 °C. However, at temperatures above 30 °C a decrease in the rate of respiration was observed with time. This 'time factor' effect progresses with rise in temperature. Based on the temperature effects fruits and vegetables can be stored for prolonged periods at low temperature.

Oxygen: We have seen that oxygen is necessary to carry out the reactions of the citric acid cycle and it is the terminal accep[tor] of electrons in this electron transport. This indicates that the rate of respiration will be affected by oxygen concentration

w oxygen concentration, both anaerobic ærobic respiration may occur in plants ting in RQ values higher than 1.00. The value becomes infinity when oxygen nt reaches zero. Under these conditions, tion of CO_2 is entirely due to anaerobic ration. When the concentration of en is increased, aerobic respiration ually replaces anaerobic respiration, lting in RQ values approaching unity.

he rate of respiration actually decreases high oxygen concentration because it tivates one or more of the respiratory ymes (e.g., aconitase) by oxidation.

arbon dioxide: An increase in CO_2 contration decreases the rate of respiration. leaves, higher CO_2 concentration results the closure of stomata thereby inhibiting s exchange.

Light: Light is known to decrease or crease the rate of respiration, the effect rying with plants.

The decrease in respiration may be caused the inhibition of oxidation of pyruvate, us affecting the Krebs cycle. The effect n the increase in the rate of respiration is ually an indirect one. Light increases the mperature, thereby influencing respiration. Light also plays an important role in the pening of stomata which facilitate exchange of gases favouring enhanced respiration.

Inhibitors: A few chemical substances hibit respiration in several ways and these have been termed *respiratory inhibitors.* Examples of such inhibitors are cyanide, carbon monoxide and malonate. As these compounds inhibit specific steps in respiration, they have helped in establishing the respiratory pathway.

TERNAL FACTORS

Some of the internal factors that affect the rate of respiration are protoplasmic conditions and the availability of respiratory substrates.

Protoplasmic conditions: Meristematic tissues which consist of non-vacuolated cells show higher rates of respiration than the older tissues which are poor in protoplasm. Not only the amount but also the various conditions of the protoplasm affect respiration.

The degree of hydration of protoplasm plays a major role in the rate of respiration. For example with an increase in the water content of a germinating seed we can observe an increase in the rate of respiration. The rate of respiration also depends on the quantity and quality of enzymes present in the protoplasm.

Respiratory substrates: Respiratory substrate is defined as a substance which can be oxidised to yield energy for growth and development. We have already noted that the most commonly used substrate in respiration is a carbohydrate. An increase in the availability of the substrates such as glucose, fructose and maltose, enhance the rate of respiration.

Respiration Associated with Photosynthetic Tissues

The respiration so far described occurs in both non photosynthetic and photosynthetic tissues, irrespective of the presence or absence of light. For this reason it is referred to as dark respiration. Lately it has been observed that leaves of many plants liberate large quantities of CO_2 in the presence of light. This light-induced evolution of carbon dioxide from photosynthetic tissue (green leaves) is known as *photorespiration*. As in dark respiration the gas that is absorbed is oxygen but the sites of photorespiration are the chloroplast and peroxisome, a cell organelle. Glycolic acid, an early product of photosynthesis, acts as the substrate whose oxidation by oxygen results in the release of CO_2.

The rate of photorespiration in fully illuminated leaves is 3 to 5 times greater than that of dark respiration. Naturally the net photosynthesis declines. Thus plants which show photorespiration are less efficient in terms of photosynthetic yield (e.g., most of the C_3 plants) than those which show little or no photorespiration (e.g., C_4 plants).

EXERCISES

1. What are NAD and ATP? Explain their role in respiration.
2. Define RQ. What is its significance?
3. What is fermentation?
4. What is oxidative phosphorylation?
5. Define photorespiration. How does it differ from dark respiration?
6. Give a brief account of the process of anaerobic respiration.
7. Discuss the mechanism of aerobic respiration.
8. In what way does temperature affect respiration?
9. How is the study of respiration related to the storage of fruits?

CHAPTER 18

Plant Growth and Development

THE process of growth results from an increase in protoplasm, leading to an irreversible increase in size and weight. This involves multiplication, expansion and differentiation of cells. Growth is associated with *differentiation* which is a change in form and physiological activity. *Development* refers to the sequence of processes in the overall life history of a cell or an organism including growth, differentiation, maturation and senescence.

In unicellular organisms growth involves increase in volume and number of organelles. Cell division serves as a means of reproduction in these organisms, and leads to increase in population. In the multi-cellular organisms, however, growth is much more complex.

The life of a flowering plant begins with the fertilised egg. Through a series of divisions an embryo is formed which is enclosed in a seed. Germination then takes place leading to the formation of a seedling. After passing through the juvenile phase, a mature plant is finally formed. After a period of vegetative growth the plant enters the reproductive stage, when with the initiation and development of flowers, fruits and seeds are formed. A new generation of plants starts again. Annual plants like wheat undergo senescence and die after bearing grain. Development associated with each of these steps is controlled by several factors, both internal and external.

Growth curve

The growth of a plant (or any organism) or organ for a definite period of time, when plotted against time forms a *sigmoid curve.* This is known as the growth curve (Fig. 18.1). An analysis of the curve shows a slow start, gradually attaining a rapid growth, followed by a period of slow growth and ultimately a decline.

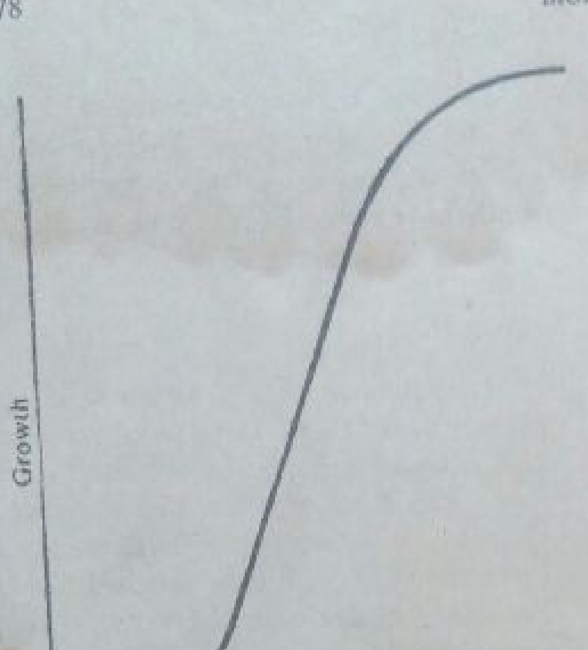


Fig. 18.1 Growth curve: stages of the growth of an organ or organism.

STAGES OF PLANT GROWTH

The growth of a plant is a reflection of cellular growth. The form and function of meristems have already been considered in Chapter 11. Cellular growth involves three main aspects: cell division, cell enlargement and cell differentiation.

Cell Division

All cells result from the division of previously existing cells. Cell division is necessary for the growth of a plant. The type of cell division that is involved in the growth of an organism is *mitosis*. During mitosis, the cell passes through prophase, metaphase, anaphase and telophase resulting in the distribution of the same number and kind of chromosomes in each of the two daughter cells formed. As a result of this process cells having the same genetic constitutions are multiplied.

Cell Enlargement

Cell enlargement has an important role in contributing to the size of the tissues and organs. In the initial stages, cell enlargement may occur in all directions but is later confined to a specific dimension. For example in the case of fibres, elongation of a cell may be several times that of the original young cell.

Cell Differentiation

Although all the cells in the plant body are derived from the zygote, they undergo structural and physiological changes depending on their location in the plant. For example, the cells of the root hair take up the role of absorption of water and salts, those in a leaf contain chloroplasts and function in photosynthesis. The sieve elements participate in the transportation of sugar and other organic substances. The xylem elements undergo characteristic changes and develop thickenings of various kinds to serve the function of conduction of water and providing mechanical strength. The term differentiation is used collectively to denote these varied changes. It is easy to trace differentiation in the different cell types. However, the precise way in which differentiation is regulated in cells with the same heredity has not been fully understood.

Factors Influencing the Mechanism and Regulation of Plant Growth and Development

The growth and development of an organism result from an interplay of a large number of factors both internal and environmental.

ENVIRONMENTAL VARIABLES

Light, temperature, and water are the more important environmental variables that affect plant growth and development.

Light

The importance of light is evident as the plant ultimately depends upon photosynthesis for its growth. Under natural conditions light accelerates growth by affecting cell division. Some of its important effects on plant processes have already been studied in the earlier chapters. Now we shall specially consider the effect of light on seed germination, seedling growth and flowering.

Before light can be utilised for the various processes in the plant, it must be absorbed by certain pigments. Chlorophylls are vital for absorption of light required for photosynthesis. Another important light absorbing pigment is *phytochrome* (blue in colour) which plays a major role in seed germination and flowering.

Seed Germination

The seeds of many of plants germinate either in light or in darkness. In some seeds light may either inhibit or retard germination. Seeds of certain varieties of tobacco and lettuce do not germinate unless they are exposed to light, at least for a short duration after they imbibe water. The quality of light that is needed is in the red region of the spectrum. If the red light treatment is followed by far-red (just outside the visible range), the seeds do not germinate. Once again, if the seeds are exposed to red light, they germinate. If this process is repeated with alternating red and far-red light, it is seen that the seeds respond to the treatment they receive at the end, *i.e.*, if the last treatment is red radiation, germination takes place and if it is the far-red, there is no germination.

Growth of Seedlings

For the proper growth of seedlings light is necessary. If they are allowed to grow in the dark they become weak, their stems become elongated and they start growing without chlorophyll. The internal tissues do not differentiate and remain mostly parenchymatous. This condition is known as the *etiolation*. Exposure of the seedlings to normal day and night conditions prevents etiolation.

Photoperiodism

The influence of the duration of daily periods of light and darkness on the phenomenon of flowering is known as *photoperiodism*. This effect was first demonstrated by Garner and Allard in 1920. Based on the influence of day length required for the flowering process, the plants are classified into *short day plants*, *long day plants*, and *day neutral plants*. Plant development is influenced by the quality, quantity, and duration of light received.

Long day plants produce flowers only when they are exposed to light periods longer than a certain critical day length (critical day length varies from plant to plant and it lies between 10 and 14 hours). Some examples of long day plants are radish (Figure 18.2), wheat, oats, sugar beets, lettuce and spinach. Short day plants produce flowers only when they are exposed to a light period shorter than that of critical day length (Fig. 18.3). Some examples of short day plants are *Chrysanthemum*, *Xanthium*, sugar cane, potato, tobacco, soyabean and *Poinsettia*. Flowering in day neutral plants is not sensitive to day lengths. A few examples of day neutral plants are tomato, cucumber, cotton, sunflower and pea.

One of the crucial discoveries has been that, when the dark period of a short day plant is interrupted by a brief exposure to light, the plant fails to flower (Fig. 18.4). This experiment has indicated that flowering is more a response to the dark period than to light. Thus short day plants can be considered as long night plants. It is interesting that light interruption of the dark period in a long day plant does not prevent flowering.

Fig. 18.2 Radish plants of the same age, illustrating the photoperiodic response of a long day species: (A) Kept under short day conditions; (B) Kept under long day conditions.

Fig. 18.3 Chrysanthemum plants of the same ag illustrating the photoperiodic response o a short day species: (A) Kept under sho day conditions; (B) Kept under long da conditions.

In fact long day plants can flower when exposed to continuous illumination.

It has been observed that red light is most active in its effect on flowering. If red light is given to a short day plant as the light breaks, it suppresses flowering. If this treatment is followed by far-red light, flower formation occurs. These types of treatments can be repeated any number of times but the effect depends upon the last treatment, i.e., if it is read, it inhibits flowering, if it is far-red it promotes flowering. The pigment responsible for making the plants sensitive to these light effects is again *phytochrome*.

Although no true substance that is res- ponsible for flowering has been isolated, has been postulated that flowering involv the production of a hormone known *florigen*. It is believed to be synthesized the leaf, which is the site of perception of th photoperiodic stimulus. From the leaf it supposed to migrate to the shoot ap or leaf axil where flowers arise. The findings are based on certain grafting exper ments.

Temperature

Growth of plants occurs usually betwe 0° and 35°C. There are plants, howev

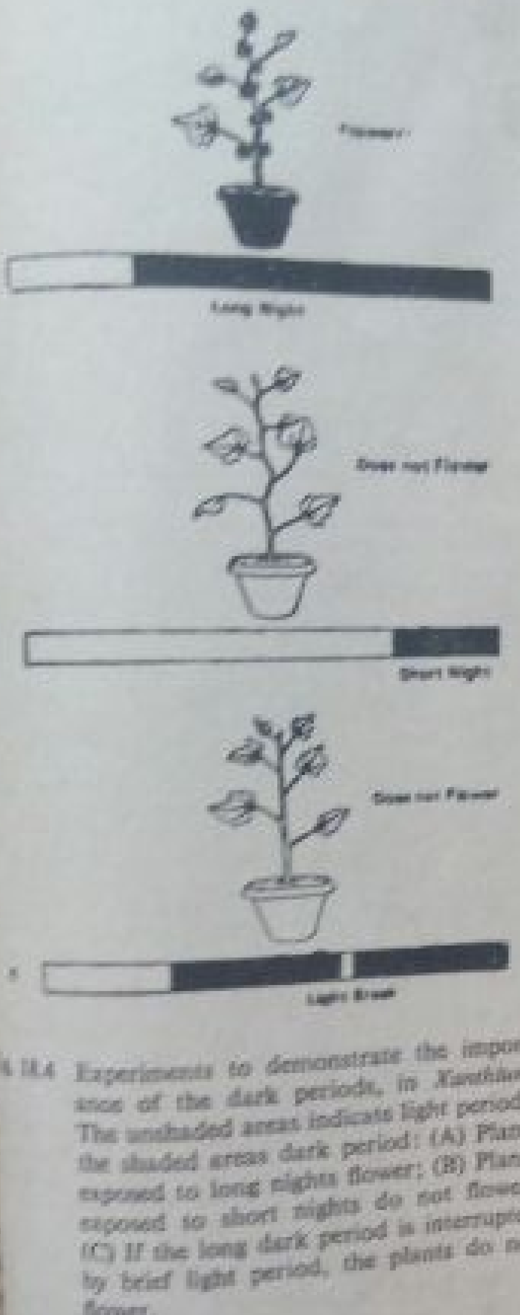


Fig. 18.4 Experiments to demonstrate the importance of the dark periods, in *Xanthium*. The unshaded areas indicate light periods, the shaded areas dark period: (A) Plants exposed to long nights flower; (B) Plants exposed to short nights do not flower; (C) If the long dark period is interrupted by brief light period, the plants do not flower.

...which have adapted themselves to grow under extremes of temperature. Temperature affects growth in three ways, the *minimum temperature* in which plant growth is very slow, the *optimum temperature*, in which plant growth is at its best and the *maximum temperature*, where plant growth is at a very much reduced rate (Fig. 18.6). The effect of temperature is not constant for all plants and varies from species to species.

In many plants temperature has a profound effect on flowering. Some plants do not flower unless they are exposed to prolonged periods of cold temperatures. Biennials remain vegetative during the first season, and after being exposed to the cold temperatures of winter, they flower in spring. However, the biennial henbane (*Hyacyamus niger*) a long day plant, can be made to flower within one growing season, provided it is exposed to low temperatures followed by the correct photoperiod (Fig. 18.5). The term vernalisation has been coined to explain the effect of chilling treatment that prepares a plant to flower.

The cold temperature treatment is effective at the seed or seedling stages. The range of temperature and the duration of exposure varies from plant to plant. For example, in *Hyacyamus niger* it ranges from 3° to 17°C for varying periods of time. Thus vernalisation prepares the plant to flower whereas the photoperiodic stimulus not only prepares the plant for flowering but also induces it. The shoot tip is the part that perceives the stimulus of cold temperatures. The stimulus is then translocated to other parts of the plant. In some plants application of gibberellin may replace the cold treatment.

INTERNAL FACTORS

The genetic make up and *growth regulators* constitute important internal factors that regulate plant growth and development. The main naturally occurring plant growth regulators are auxins, gibberellins, cytokinins, ethylene and abscisic acid. The first four are called plant hormones. **ABA** is a naturally occurring growth inhibitor. These substances occur in small quantities and control many of the physiological processes involved in plant development.

Auxins

Among the growth hormones, auxins were the first to be discovered and studied in

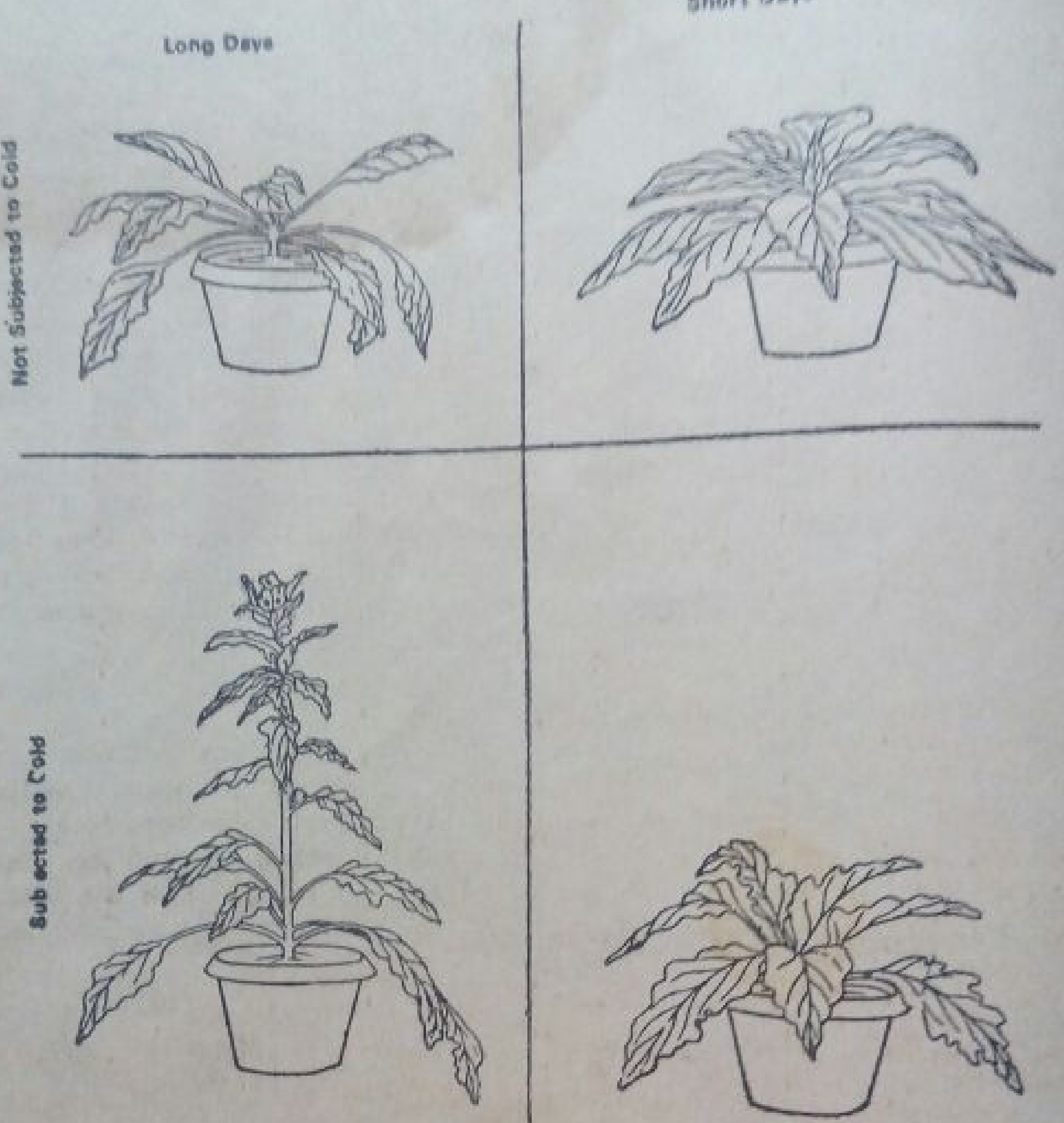


Fig. 18.5 Flowering response in henbane (*Hyocyamus niger*), a long day plant under different conditions of temperature and light.

detail. In 1928, Went demonstrated its effect on plant growth by performing some experiments with the oat coleoptile (Fig. 18.7). When the tips of the coleoptiles were removed no conspicuous growth took place. When the freshly cut coleoptiles were placed on agar blocks for a few hours (during this period auxin diffused into the agar block) and then the agar blocks were placed on the cut ends on the coleoptiles, growth occured. If an impregnated agar block was placed laterally on the cut tip of a coleoptile only that side of the coleoptile elongated resulting in a curvature. These experiments indicated that auxin is synthesised in the coleoptile tip and is translocated downward.

Among the several types of auxins Indole-3-acetic acid (IAA) is the most well-studied and important natural auxin.

Auxins are synthesized in the shoot tips, young leaf primordia, developing seeds and from there they migrate to the regions of elongation. The movement of auxin is polar and in stems it takes place in a basipetal direction

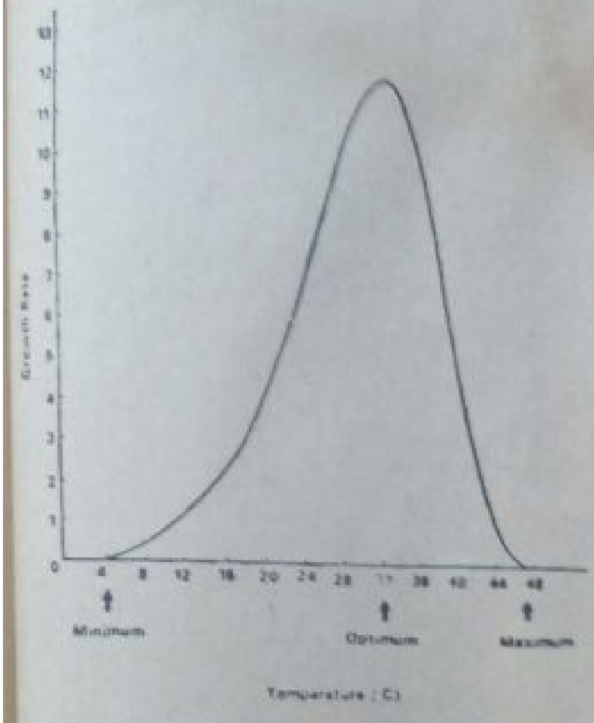


Fig. 18.6 Effect of different temperatures on the growth of maize seedlings.

acropetal direction. Auxins cause elongation of the stems and roots.

Different parts of the plant respond differently to the concentration of auxin (Fig. 18.8). In roots, low concentrations stimulate growth but any increase will result in retardation. In the figure, we can see that the concentrations which increase stem growth retards the growth in roots. High concentrations inhibit stem growth also.

One of the main functions of auxins is the promotion of cell elongation. The presence of auxins in the shoot apex suppresses lateral bud growth. This is called apical dominance. If the apex is removed, the inhibition of lateral buds is removed. Auxins play an important role in the initiation of roots, cambial activity, development of fleshy fruits, delaying the leaf drop and fruit drop. Auxins in combination with cytokinins play a role in cell division.

Gibberellins

Gibberellins were first identified and isolated from the fungus *Gibberella fujikuroi* which causes 'foolish seedling disease' in rice plants in Japan. Infection of their roots caused excessive elongation of the plants. Many types of gibberellins have been isola-

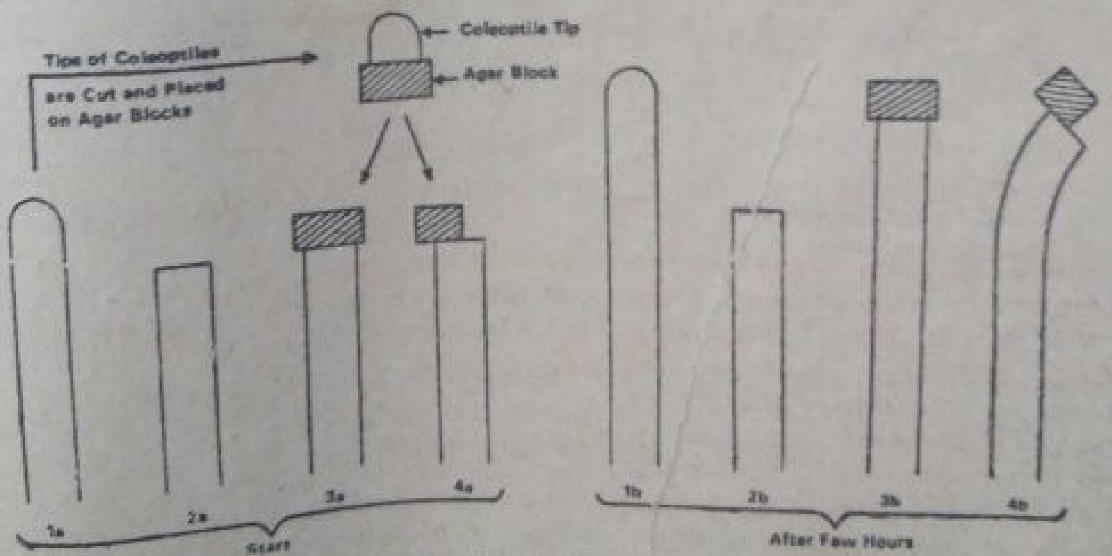


Fig. 18.7 Oat coleoptile experiments. Oat coleoptile with its tip intact showed growth (1*a* and 1*b*). Decapitated coleoptile shows no growth (2*a* and 2*b*). Agar block impregnated with auxin from cut coleoptile tip, when placed on decapitated coleoptile growth resumes (3*a* and 3*b*). When the impregnated agar block is placed laterally, growth occurs only on one side resulting in curvature (4*a* and 4*b*).

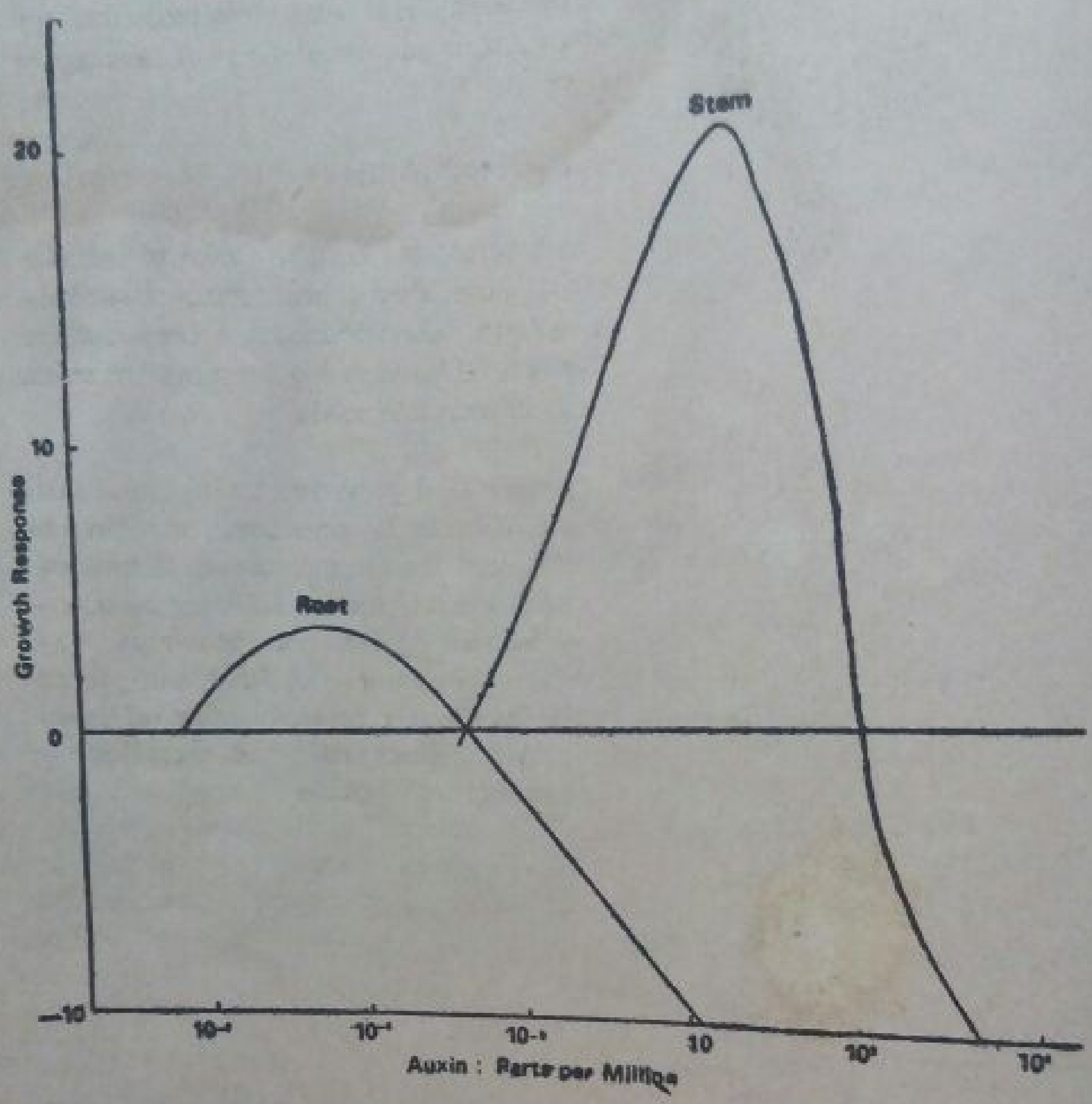


Fig. 18.8 Ro t and stem responses to varying concentrations of auxin.

ted among which GA_3 (gibberellic acid) is more well studied and most common in plants.

Gibberellins cause stem elongation (Fig. 18.9). When the genetic dwarf plants are treated with gibberellin, they become tall. Gibberellins promote seed germination and break dormancy of buds and tubers. They promote flowering of long day plants under non-inductive conditions. They increase leaf and flower size in many plants. They also induce parthenocarpy (seedless fruits). In the germinating grains of cereals like barley gibberellins stimulate the formation of α-amylase, responsible for the hydrolysis of starch.

Cytokinins

The main function of cytokinins is cell division. Skoog and his co-workers have done pioneering work on cytokinins. Endosperm of seeds and roots are the sites of synthesis of cytokinin. Its effect on cell division takes place in combination with auxin. Kinetin is a degradation product of DNA and does not occur naturally. The most well-studied naturally occurring cytokinin is zeatin, isolated from

Cytokinins are also involved in cell expansion, and retardation of ageing of leaves.

Abscisic Acid (ABA)

In contrast tc the growth hormones discussed above, abscisic acid retards or suppresses growth. Abscisic acid has been isolated from several parts of higher plants including dormant buds and seeds.

Abscisic acid promotes leaf fall and dormancy of buds. In some seeds, it is present in the seed coats and causes dormancy. Many of the activities of ABA are reverse to those induced by GA_3 and cytokinins. ABA decreases the synthesis of RNA and protein in the leaves. It promotes ageing of leaves. It inhibits the formation of α-amylase in germinating cereal grains.

Fig. 18.9 Cabbage plants of the same age; (A) Control; (B) GA treated.

EXERCISES

hat is differentiation?
plain the growth curve.
fine growth. Describe growth at the cellular level.
cribe the important factors that affect growth and development of plants.

CHAPTER 19

Plant Movements

SOME lower group of plants which live in water show characteristic locomotory movements. Higher plants whether growing in the soil or occurring freely in water do not show locomotion but show only growth movements. One important feature of these movements is that they are generally very slow. The usual forms of growth movement are *bending*, *twisting*, and *elongation* of certain organs. The movements mostly result from external stimuli and depend upon the ability of the plant organs to respond to them.

The length of time necessary for a stimulus to induce a response is termed *presentation time*. The length of time that is required by a plant to manifest its response to a stimulus is termed *reaction time*. The time required for the response stimulation to disappear is known as *relaxation time*. If a series of stimulations are given without sufficient time for the plant or the plant organ to recover between the successive stimuli, the plant fails to respond and the tissues concerned are said to be in a state of fatigue.

The movements exhibited by the organs of plants are classified into three groups: (1) *growth movements* caused by changes in the position of the organs due to enlargement of cells, or increase in the number of cells, or both; (2) *turgor movements* caused by reversible changes in cell volume; and (3) *hydration movements* concerned usually with non-living plant tissues or organs and resulting from hydration or dehydration of the cell walls. Here we deal with some of the growth and turgor movements that occur most commonly in plants.

Growth Movements

Growth movements are divided into three sub-groups: (1) *Tropic movements* occur in response to an unidirectional stimulus. The response is always related to the direction of the stimulus. Examples are *Geotropism* and *Phototropism*. (2) *Nastic* movements in which

...ponse has no relation to the direction ...e stimulus. It is diffuse (example, ...asty). (3) *Nutation* is a movement ...is usually independent of the environ- ...l factors. It is characterised by spiral ...of growth of the shoot apex.

...ROPISM

...otropism is the tropic movement induced ...avity. The direction of the response is ...ent in different parts of the plant. If ...response is towards the stimulus of ...y it is termed *positive geotropism* and ...ay from it, *negative geotropism*. Positive ...opism is observed in primary roots ...19.1). Negative geotropism (Fig. 19.2) ...und in coleoptiles, most hypocotyls, ...and pneumatophore roots of man- ...s (Fig. 19.2). If the organ becomes ...ed at an angle to the force of gravity it ...own as *plageotropism* and if this angle is ...t angle, it is known as *diageotropism*. ...ples of plageotropism are secondary ...and lateral stems and those of diageo- ...m are many dorsiventral leaves and ...mes.

...at particles in the cells perceive the ...lus (receptors) is not clearly known, ...gh there is some evidence that statolith ...grains may be responsible.

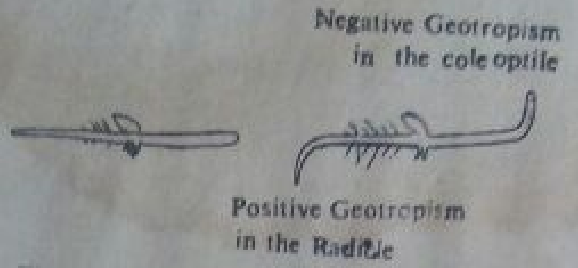
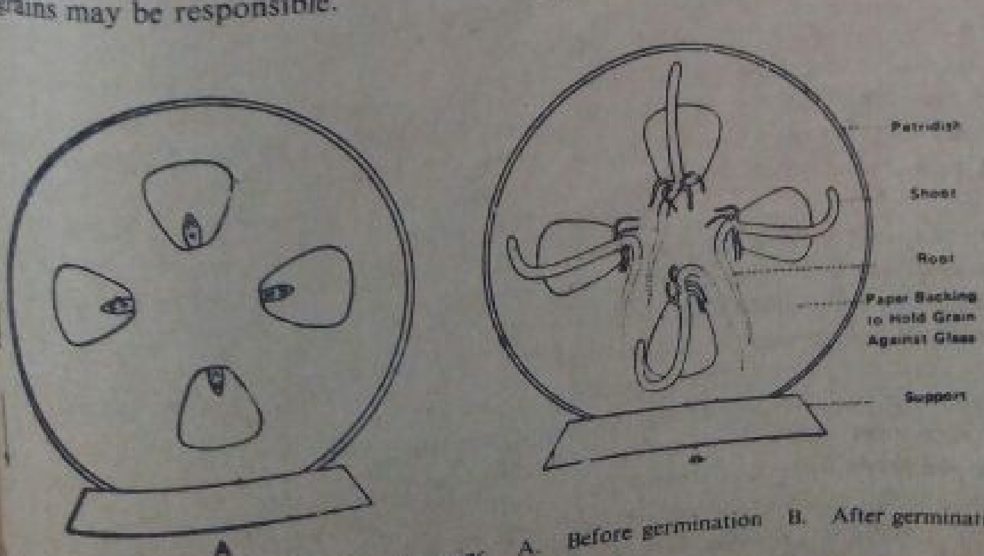


Fig. 19.1 Horizontally-placed oat seedling showing geotropic responses.

The geotropic curvature occurs some distance behind the apex, and at the elongating region and is mostly controlled by the amount of auxin accumulating there. When the primary root and stem are placed horizontally, more auxin accumulates on the lower side than on the upper. The different auxin concentrations cause differential growth in the upper and lower sides. Stems and roots exhibit different auxin sensitivities as a result of which curvatures are manifested. The concentration of auxin that accumulates on the lower side accelerates growth in the stem and retards it in the root. So more elongation of the cells on the lower side of the stem results in an upward curvature whereas in the root, there is relatively greater growth inhibition in the lower side than in the upper, resulting in a downward curvature.



...19.2 ... ...uting maize grains. A. Before germination B. After germination.

PHOTOTROPISM

Phototropism is tropic movement induced by light (unilateral illumination). The direction of response again varies in the different parts of the plant. If the direction is towards the light source, it is called *positive phototropism* and if bends away from it, *negative phototropism*. If the organ becomes oriented at right angles to the path of light it is called *diaphototropism*. Primary stems, coleoptiles exhibit positive phototropism and some primary roots negative phototropism. Most of the leaves exhibit *diaphototropism*.

As in the case of geotropism the responses are observed in young elongating zones and are caused by unequal growth rates on the two sides of the stem. This again takes place mostly by an unequal distribution of auxin on the illuminated and shaded sides. The greater accumulation of auxin of the shaded side causes more elongation of the cells on that side resulting in a curvature towards the source of light, because it happens to be a light-mediated process. Light is absorbed by a pigment present in the stem apex and it is most probably carotene.

Turgor Movements

It was observed that in geotropism and phototropism the movements are caused by a permanent increase in the size and number of cells in the tissues concerned. In the case of turgor movements which are based on the turgor pressure of the cells, movements are caused only by reversible changes in cell size. Thus volume changes in cells result in movements. Examples of turgor movements are folding or rolling of grass leaves, sleep movements of leaves of leguminous plant that occur at night and the closure of leaflets of *Mimosa pudica* (sensitive plant) caused by touch.

The folding and rolling of grass leaves result from the turgor changes of bulliform cells that are located in the upper epidermis. When the turgor pressure is high, these cells distend and spread the leaf blade. When the turgor pressure decreases the leaf folds due to the pressure extended by the cells of the lower side.

The closure of the leaves of *Mimosa pudica* by external stimuli such as physical contact, injury, electrical shock etc., is due to the turgor changes that occur in the *pulvinus* of the leaf. Pulvini are structures present in most of the plants belonging to *Leguminoseae*. They are located at the base of the petiole and at the point of attachment of the leaf blade to the petiole. These structures are dominated by thin walled parenchyma cells with intercellular spaces. As a result of external stimuli, the ejection of liquid into the inter-cellular spaces of the pulvinus takes place resulting in closure of the leaves. It has been observed that during this process potassium ions (K^+) play a major role. In its reversible process, the cells of the pulvinus regain turgor and the leaves attain the normal position.

EXERCISES

1. Describe various growth movements in plants.
2. What are turgor movements? Give examples and explain.

Section II

External Morphology: Plants

CHAPTER 20

Vegetative Morphology— Root, Stem and Leaf

This knowledge of external morphology of angiosperms is essential for the study of all branches of botany in general and anatomy, physiology and systematics in particular. It is only after studying the variations in forms, that the evolutionary processes can be understood. A typical angiospermic plant has a distinct underground root system and an aerial shoot system (Fig. 20.1). The shoot system consists of branched or unbranched stem bearing leaves. The reproductive shoot is the flower with its differentiated organs which is essentially concerned with the reproduction in plants.

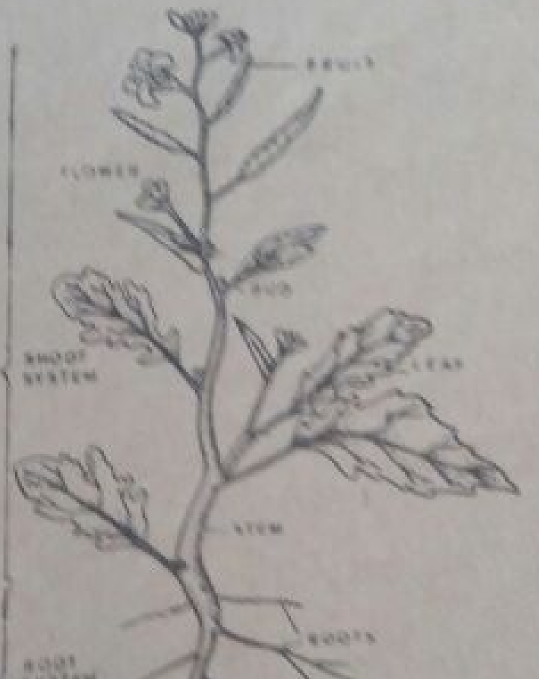


Fig. 20.1 Common flowering plant showing different parts.

Root

When the primary root, which is a direct prolongation of the radicle, remains distinct throughout the life of the plant and gives off lateral branches, it is termed as the *tap root system* e.g. Mustard (Fig. 20.2 a). However,

in many plants the root grows from any other part of plant other than original root system. It is called the *adventitious root system* (Example: onion, grasses (Fig. 20.2b). Besides their usual function of anchorage and absorption, they may also be suitably modified to carry out several other functions.

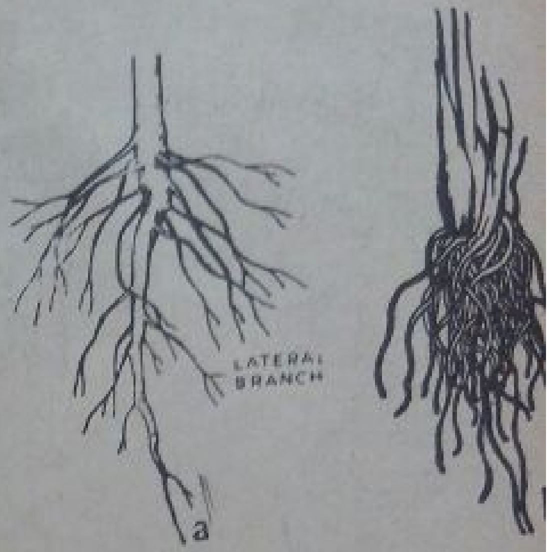


Fig. 20.2 a. Tap root system
b. Adventitious root system.

MODIFICATIONS OF TAP ROOT

In many plants the tap root becomes swollen and assumes various forms. This happens due to the storage of food. The

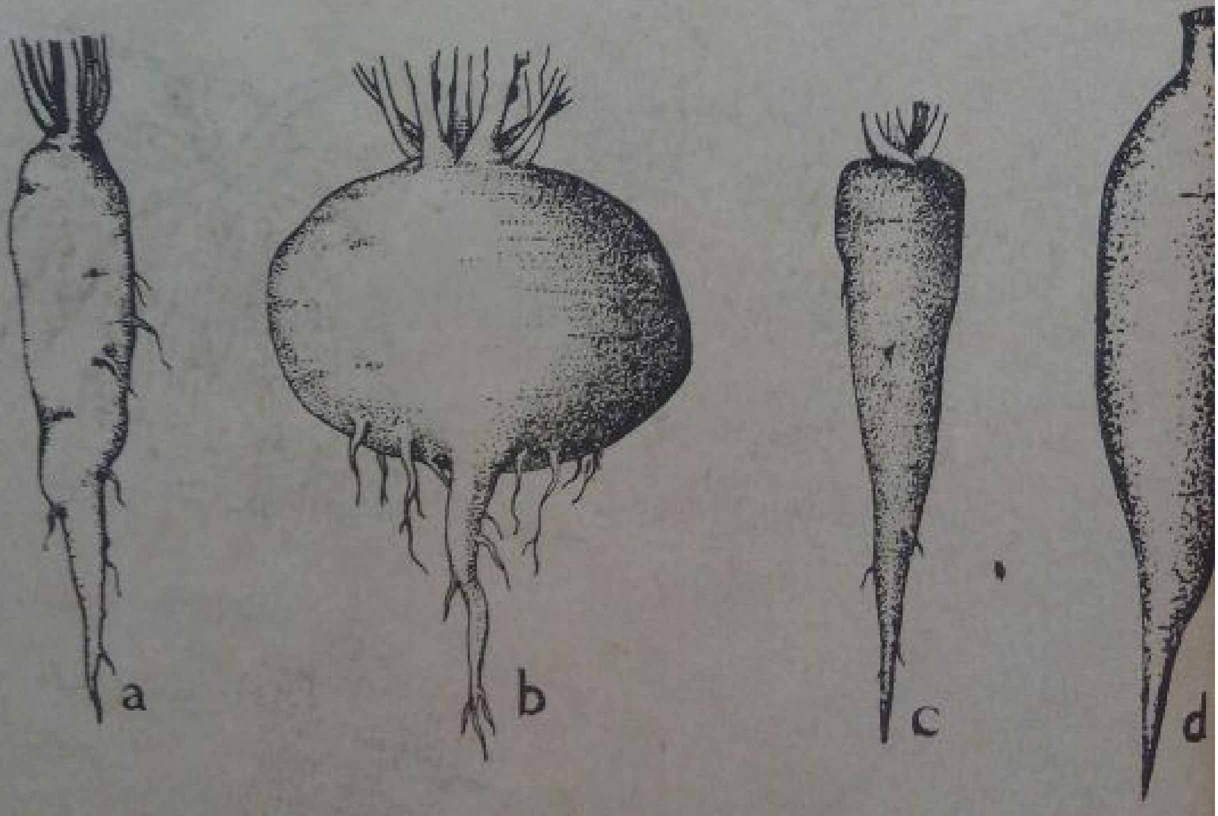
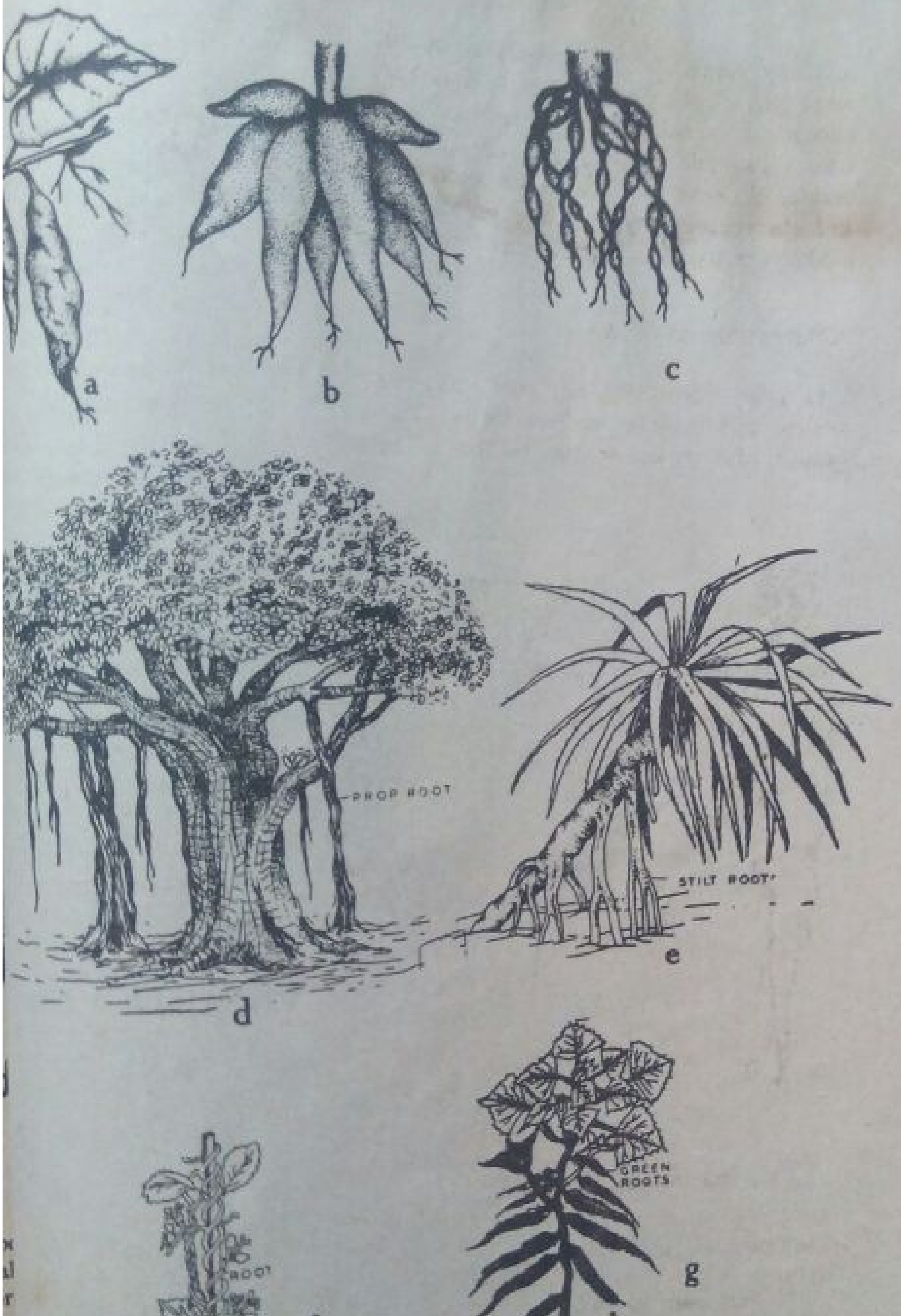


Fig. 20.3 Modifications of tap root a. Fusiform b. Napiform c. Conical d. Tuberous.

modifications may be of the following types:

(1) *Fusiform:* Here the root tapers gradually at both the ends but is swollen in the middle. Example: Radish (Fig. 20.3a.).

(2) *Napiform :* When the shape the primary root becomes alm spherical and tapers abrup downward, it is said to be na form. Example: Turnip (Fi 20.3b)



...4 Modifications of adventitious root
...Tuberous b. Fasciculated c. Beaded d. Prop e. Stilt f. Parasitic g. Assimilatory.

(3) *Conical:* Here it is cone-like structure. Example: Carrot (Fig. 20.3c).

(4) *Tuberous:* Here the swollen root has no specific shape. Example: *Mirabilis* (Fig. 20.3d).

MODIFICATIONS OF ADVENTITIOUS ROOT

Likewise, adventitious root may be modified to carry on the storage of food, mechanical support and other vital functions. Some of the main types are:

(1) *Tuberous:* Here again the swollen root is shapeless and occurs singly. Example: Sweet potato (Fig. 20.4a).

(2) *Fasciculated:* When several tuberous roots occur in a cluster arising from the same place. Example: *Asparagus, Dahlia, Ruellia* (Fig. 20.4b).

(3) *Beaded:* Here the adventitious roots have swollen regions at frequent intervals. Example: *Portulaca, Momordica.* (Fig. 20.4c).

(4) *Prop :* They are pillar like structures and hanging vertically downward from the aerial branches. Example: Banyan tree (Fig. 20.4d).

(5) *Stilt:* These are short roots growing obliquely from near the base of the main stem and provide additional support (Fig. 20.4e). Example: Maize, Sorghum, Sugarcane, Screwpine.

(6) *Parasitic:* Parasitic plants develop roots which penetrate into the host-tissue and suck the nutrients. Example: *Cuscuta* (Fig. 20.4f).

(7) *Assimilatory :* In some plants, adventitious roots arise from the aerial stem, become green and photosynthesise. Such roots are known as assimilatory roots. Example: *Tinspora, Trapa* (Fig. 20.4g).

Stem

The stem is the ascending aerial portion of a plant and develops from the plumule. It is differentiated into nodes and internodes and bears leaves, branches and flowers. It is usually erect, rigid and strong. The growing apex of the stem is covered with a number of small leaves. Leaves and branches develop from the nodes. However, stems may be weak and may trail prostrately on the ground or climb. In contrast to the root, they possess buds which may be situated in the axil of the leaf or terminally. A bud is a young undeveloped condensed shoot consisting of a short stem and a number of tender leaves arching over its growing apex.

The habit of the plant is displayed by its stem. It is determined by its height, duration and nature. *Herbs* are small plants with soft stem. Medium sized plants with hard and woody stems, that branch profusely to attain a bushy appearance, are called *shrubs*. Trees are plants having stout and long trunks with profused branching. According to their life span the plants may be *annuals*, *biennials* and *perennials*. Plants, which complete their life-cycle in one season only are termed annuals such as rice, sunflower, etc. Biennials complete their life-cycle in two seasons (e.g. radish, cabbage). Plants that usually survive for a number of years and produce flowers and fruits during specific period each year are termed perennials. Example: Mango, Bamboo.

MODIFICATIONS OF STEM

Besides their usual function of bearing leaves and flowers, stems often get modified to perform other functions such as perennation and vegetative propagation. As a

heir forms are greatly changed. three types of modified stems:

ground modifications of stem

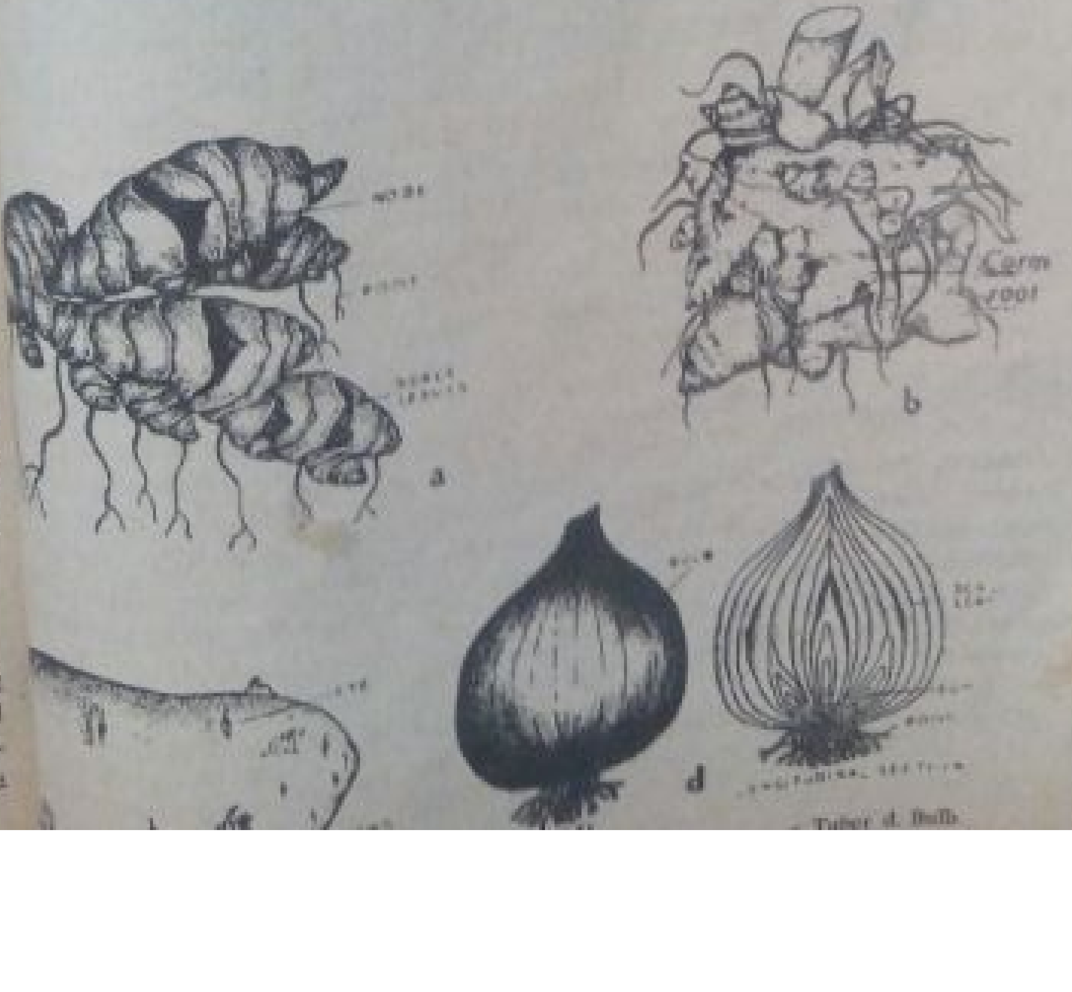
the purpose of perennation and of food, stems of some plants become ntly burried in the ground and e to aerial shoots annually under le conditions. They appear like t are distinguishable from the latter g scale leaves at the nodes and buds. ms also act as a means of vegetative ion. The important types of under- tem are:

(i) *Rhizome:* It is a prostrate and thickened stem, growing horizontally under the soil. Nodes are marked as rings, bearing scale leaves in their axils. Branches and buds are also present. Adventitious roots arise from their underside. Example: Ginger (Fig. 20.5a).

(ii) *Corm:* It is like a *rhizome* but grows vertically and is spherical to oval in form. It is rarely branched. Example: *Amorphophallus* (Fig. 20.5b).

(iii) *Tuber:* A tuber is the swollen end of a specialized underground branch. It is usually spherical and has distinct notches known as 'eyes'. These 'eyes' are, in fact, axillary buds. New plants arise from these buds. Roots are absent. Example: Potato (Fig. 20.5c).

(iv) *Bulb:* Here the stem is highly condensed and discoid bearing a large number of fleshy scale-leaves. It possesses terminal bud in the centre which gives rise to an aerial shoot



... Tuber d. Bulb

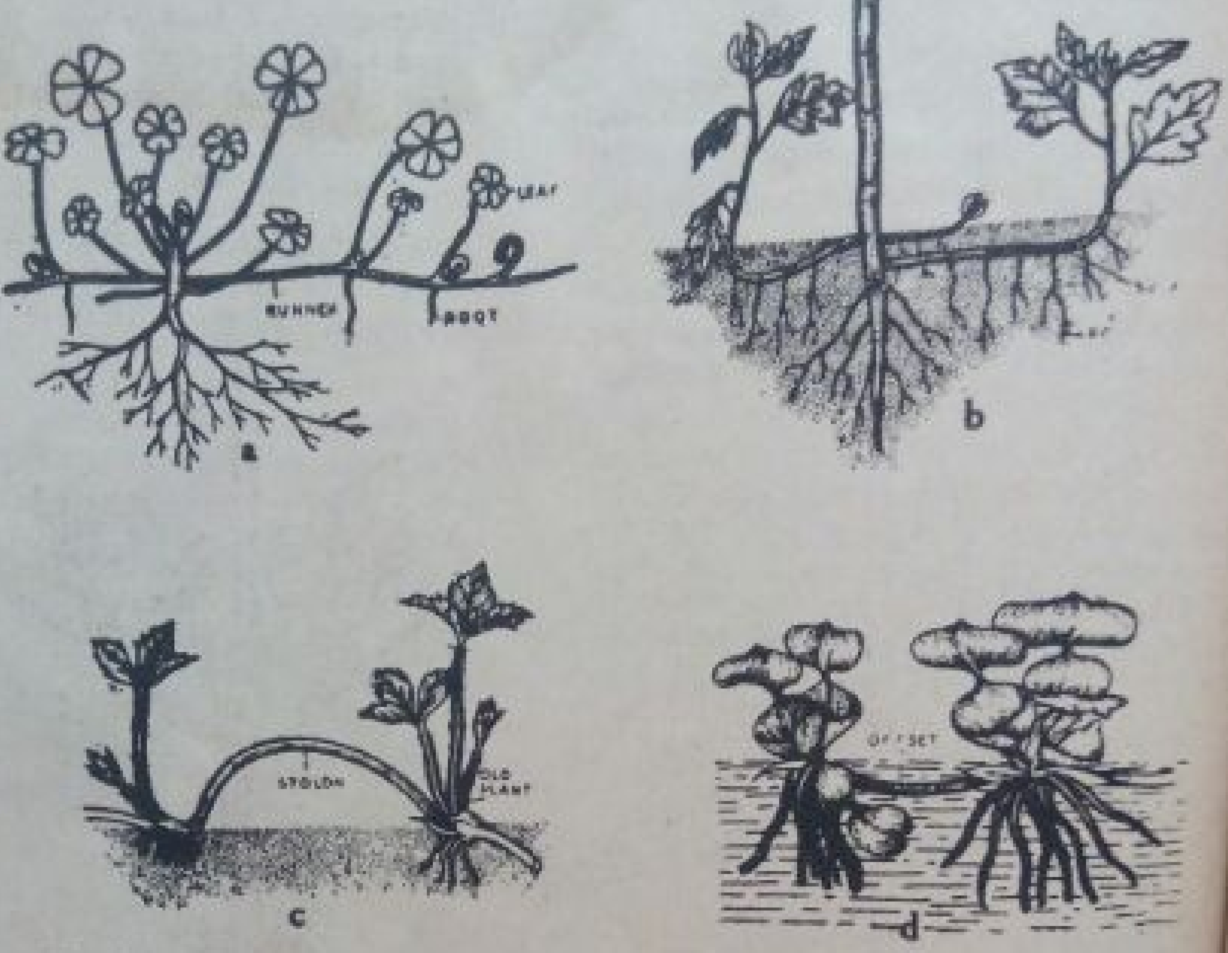


Fig. 20.6 Sub-aerial modifications of stem a. Runner b. Sucker c. Stolon d. Offset

that produces flowers. Axillary buds are also present. A cluster of adventitious roots is present on its underside. Example: Onion (Fig. 20.5d).

(2) Sub-aerial modifications of stem

In some cases, stems are normally weak, prostrate and touch the ground or are burried superficially in the soil. Aerial branches and adventitious roots develop at the nodes, which may behave as an independent plant when detached. Such plants are commonly known as creepers. They are of the following types:

(i) *Runner:* This is a creeping stem with long internodes, running horizontally on the surface of the soil. Roots are given out at the nodes. Axillary buds form new aerial shoots (Fig. 20.6a). Example: Doob gras (*Cynodon* sp.), *Oxalis*.

(ii) *Sucker:* This is like a runner but originates from the basal and underground portion of the main stem. It grows horizontally beneath the soil but soon comes out upward obliquely bearing the leafy shoot. Suckers are shorter and stouter than runners (Fig 20.6b). Example: Mint, *Chry-santhemum*.

(iii) *Stolon:* This is a slender lateral branch arising from the base of the main axis which after growing horizontally for sometime arches to touch the ground. There its terminal bud gives rise to a new shoot and roots (F

Offset: It occurs in aquatic plants like *Eichhornia* (Fig. 20.6d). It is like a runner with short internodes. Each node bears a rosette of leaves and a tuft of roots.

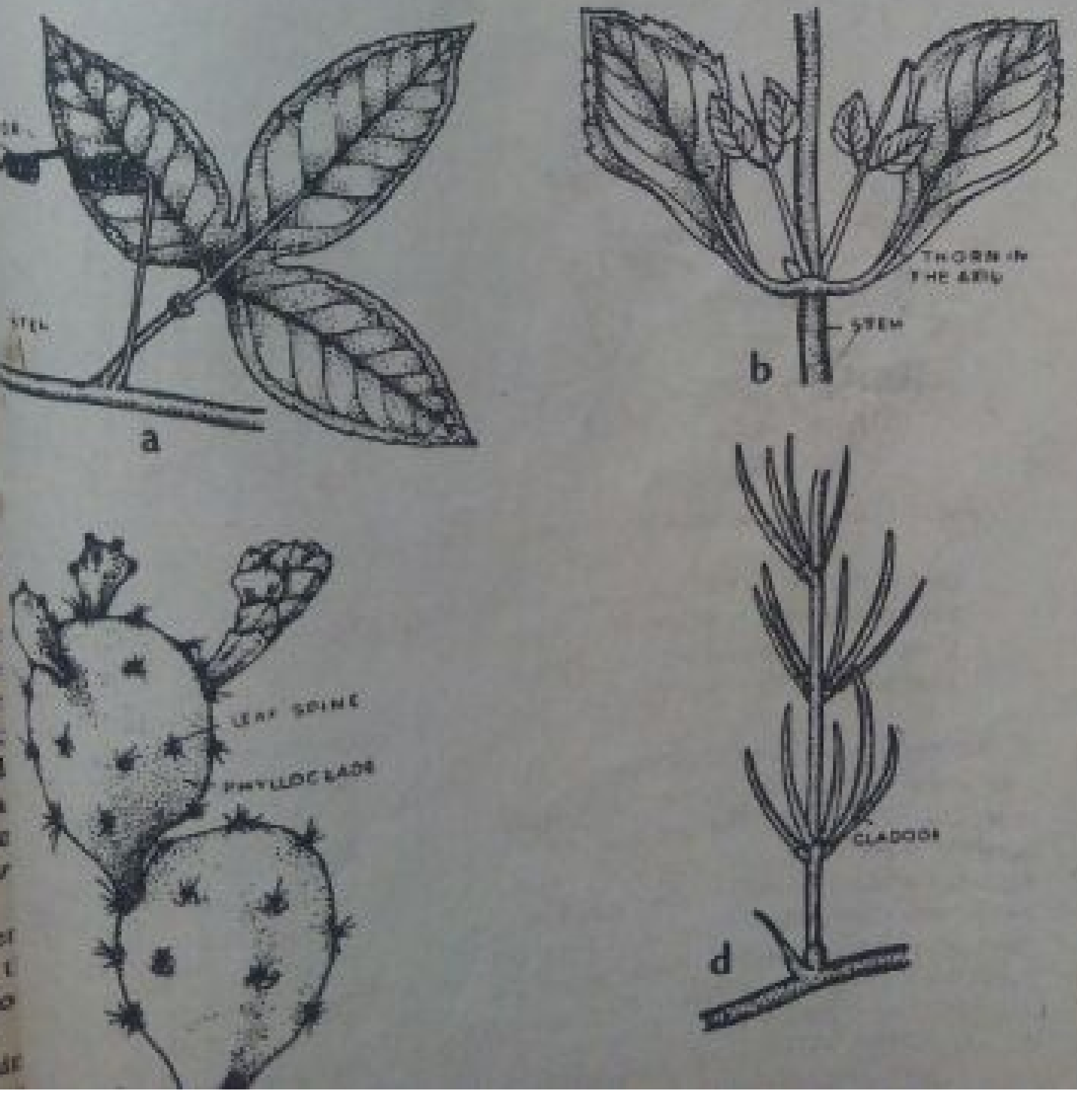
ial modifications of stem

modified stems perform unusual ns and are aerial in position. They y vary in form but can be distinguished by their position in the axil of a leaf the apex:

Stem-tendril: It is a thread like, slender and spirally coiled structure that helps the plant in climbing (Fig. 20.7a). Example: Passion flower (*Passiflora*).

(ii) *Thorn:* It is a hard woody, straight and pointed structure present in the axil of a leaf. It sometimes bears leaves also. It is protective in nature. Example: *Duranta.*

(iii) *Phylloclade:* Here the stem is cylindrical, flattened, develops chlorophyll and performs the function of leaves



as well. It has several nodes and internodes. Actual leaves are usually reduced to spines. It is fleshy and characteristic of xerophytes (Fig. 20.7c). Example: Cactus (*Opuntia*), *Euphorbia*.

(iv) *Cladode:* It is a phylloclade with one or two internodes only, and resembles a leaf. It arises in the axil of a much reduced scale-leaf (Fig. 20.7d). Example: *Asparagus, Ruscus*.

Branching of the stem

In higher plants, new branches arise from the sides of the main stem. This type of branching is known as lateral and is of two types.

(1) *Racemose:* This is also known as indefinite or monopodial type. Here the main stem continues to grow indefinitely by its terminal bud, giving off lateral branches. The mode of branching is termed *acropetal*. Older branches are at the base and the younger ones at the apex (Fig. 20.8a). Example: *Casuarina*, Ashok tree (*Polyalthia*).

(2) *Cymose:* In this type the terminal bud of a branch ceases to grow but lateral branches, varying in number, soon develop and grow vigorously from below (Fig. 20.8b). The mode of branching is thus basipetal. Depending upon the number of branches appearing at a time, it has been further classified into *uniparous, biparous* and *multiparous* types. Exam-

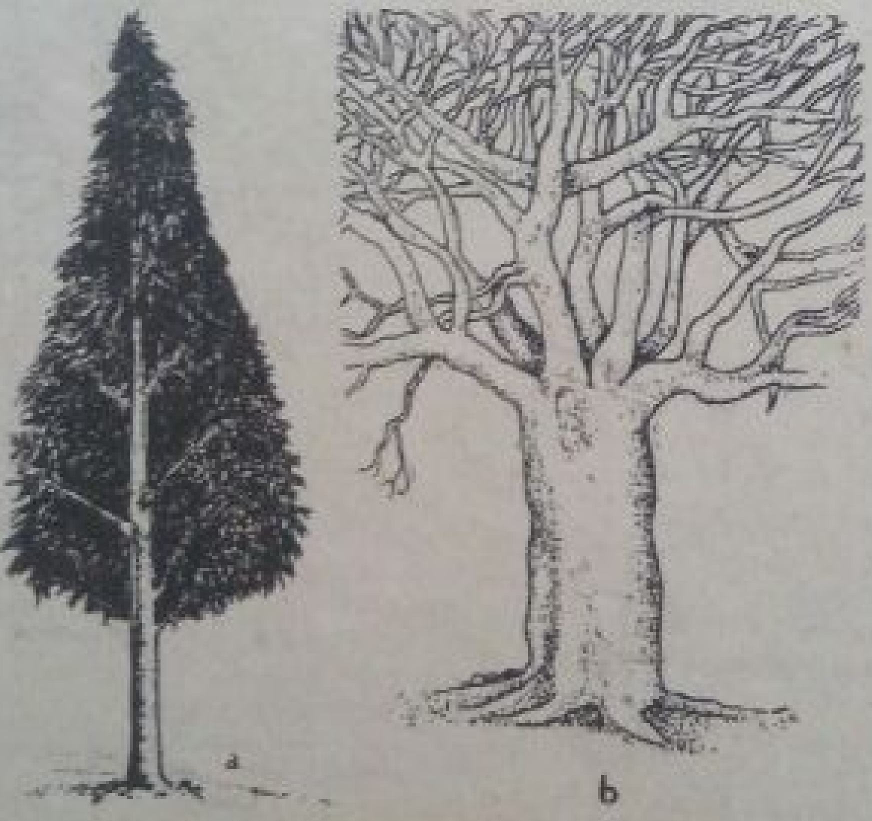


Fig. 20.8 Types of stem branching a. Racemose b. Cymose

ple: *Datura*, *Carissa*, *Croton* respectively.

Leaf

The leaf is a flattened lateral outgrowth of the stem and bears a bud in its axil. It is green in colour due to the presence of chlorophyll and constitutes the main photosynthetic organ of the plants. They develop acropetally and exogenously.

Parts of a typical leaf

A typical angiospermic leaf (Fig. 20.9) consists of three parts, namely (1) a leaf base, (2) a petiole and (3) a lamina.

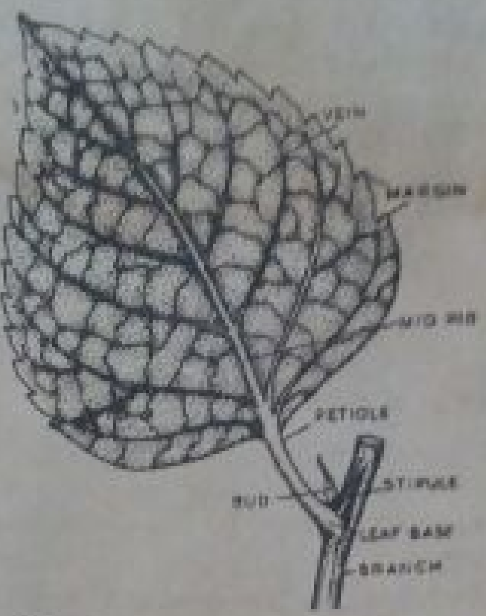


Fig. 20.9 Common leaf showing various parts

(1) Leaf base

It attaches the leaf with the stem. In monocotyledons the leaf base expands into a sheath that partially or wholly covers the stem (Fig. 20.10a) while in many dicotyledonous plants it bears two lateral outgrowths called the stipules. Depending on the presence or absence of stipules, a leaf may be stipulate or exstipulate. In many plants the leaf base is swollen and is termed *pulvinus* (Fig. 20.10b). Stipules vary in forms and may be of the following types:

(*a*) *Free-lateral:* Free-lateral stipules are small and greenish outgrowths one on either side of the leaf base as in China-rose (Fig. 20.11a).

(b) *Foliaceous:* When the stipules are large, green and leaf-like in structure, they are known as foliaceous (Fig. 20.11b) as in sweat pea and pea.

(c) *Adnate:* The two stipules adhere to the petiole to a certain height and the structure is wing-like in appearance. Example: Rose (Fig. 20.11c).

(*d*) *Ochreate:* Here the stipules form a tubular structure covering the stem above the node as in *Polygonum* (Fig. 20.11d).

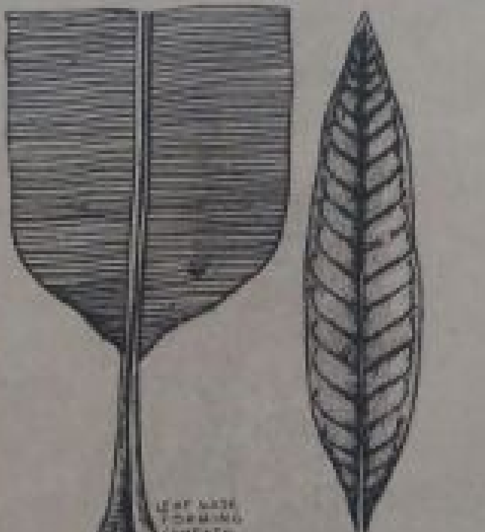


Fig. 20.10 Shape of leaf base
a. Leaf base expanded to form sheath
b. Swollen leaf base (pulvinus)

(2) Lamina

It is the green, expanded portion of the leaf and is traversed by a number of veins

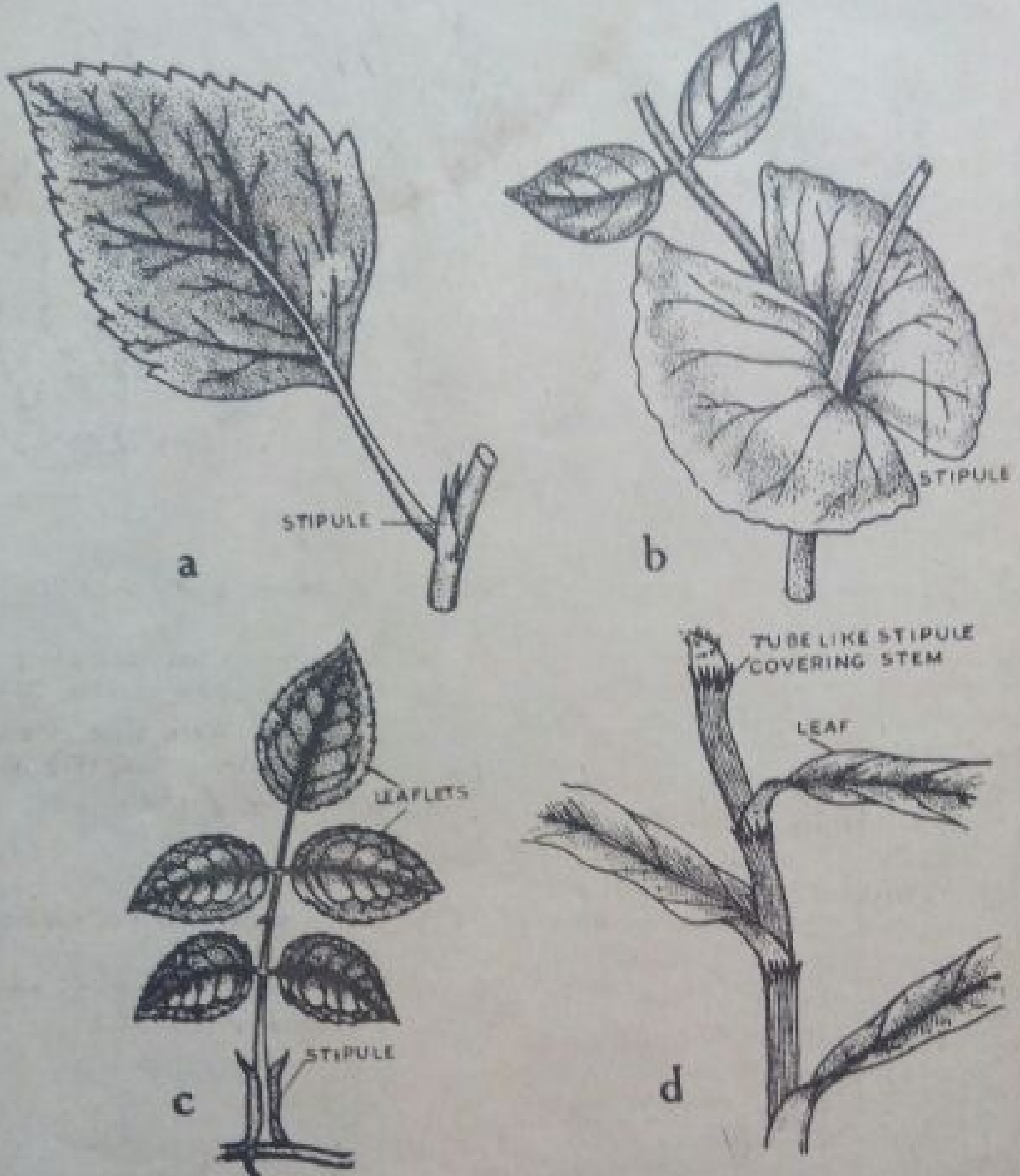


Fig. 20.11 Different types of stipules a. Free-lateral b. Foliaceous c. Adnate d. Ocherate

and veinlets. There is usually a middle prominent vein which is known as the mid-rib. Veins provide rigidity to the lamina and act as channels of transport of the food materials in and out of the leaf. The shape of the lamina varies from plant to plant which may be of the following types:

(i) *Linear*—When it is long, narrow and

(ii) *Lanceolate*—When it is lance-shaped as in bamboo (Fig. 20.12b).

(iii) *Oblong*—When it is wide and long as in banana (Fig. 20.12c).

(iv) *Ovate*—When it is broader at the base and narrower at the apex (Fig. 20.12d) as in China-rose, banyan.

(v) *Cordate*—When it is heart-shaped as

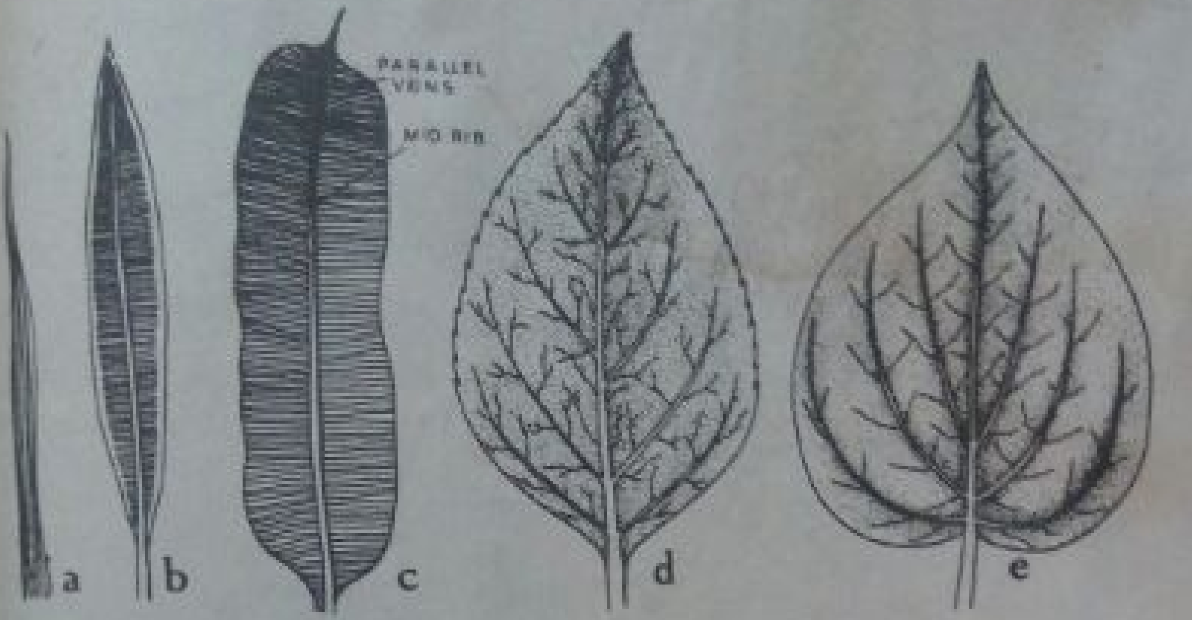


Fig. 20.12 Shape of lamina a. Linear b. Lanceolate c. Oblong d. Ovate e. Cordate

Leaf-apex

The tip of the lamina is described as apex. It is also of several types, such as:

(i) *Acute:* When it is pointed but not stiff. Examples: China-rose (Fig. 20.13a).

(ii) *Cuspidate:* When it is a pointed hard, stiff and spiny structure as in date-palm (Fig. 20.13b).

(iii) *Obtuse:* When it is rounded as in banyan (Fig. 20.13c).

(iv) *Acuminate:* When it is long and tapering as in peepal (Fig. 20.13d).

(v) *Emarginate:* When there is a deep notch, bifurcating the tip (Fig. 20.13e) as in kachnar (*Bauhinia*).

Margin

The margin or the outline of the lamina is quite variable, such as:

(i) *Entire:* When it is even and smooth as in mango (Fig. 20.14a).

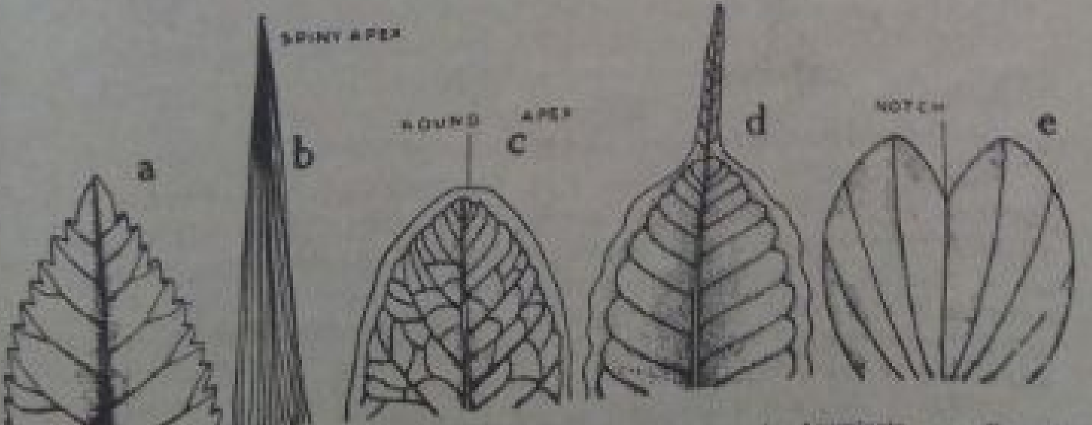


Fig. 20.13 Leaf-apex types a. Acute b. Cuspidate c. Obtuse d. Acuminate e. Emarginate

Fig. 20.14 Variations in outline of the lamina
a. Entire b. Wavy c. Serrate

(ii) *Wavy:* When the outline although smooth, is wavy (Fig. 20.14b) as in Ashok tree (*Polyalthia*).

(iii) *Serrate:* When the margin is like the teeth of a saw (Fig. 20.14c) as in China-rose, rose.

Venation

The arrangement of veins in the lamina is termed as venation. It is of two types:

(1) *Reticulate:* When the veins are irregularly distributed forming a net work, it is known as reticulate venation. It is a characteristic feature of the dicotyledons. Example: Peepal, China-rose (see Fig. 20.14c).

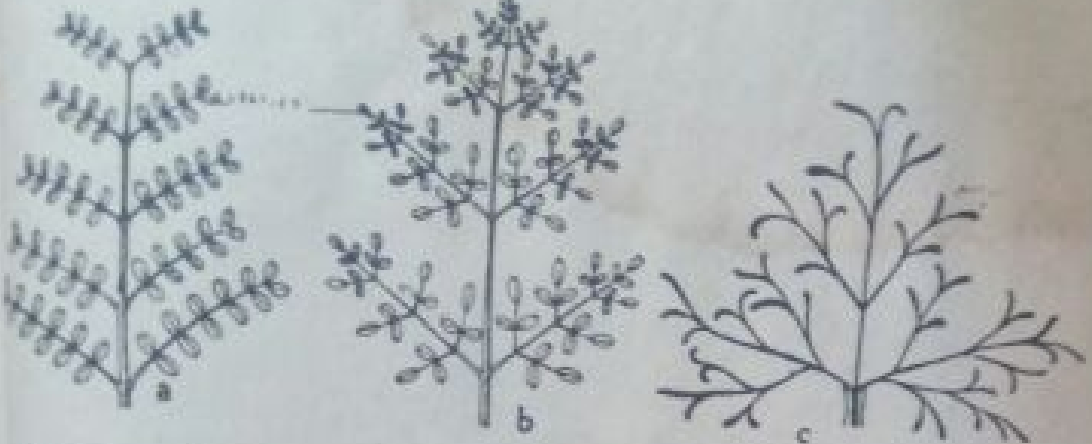
(2) *Parallel:* When the veins are parallel and do not form a network. The venation is called parallel, as in *Canna*, grasses. Parallel venation is characteristic feature of the monocotyledons (see Fig. 20.12a,b,c).

In both the types often, a prominent mid-vein is observed, in that case it is described as unicostate. Example: Peepal, Mango, *Canna*. There are also leaves with more than one prominent vein as in plums (*Zizyphus*), fan palms. It is said to be multicostate.

Simple and Compound Leaves

A leaf is said to be simple when its lamina is entire or incised but the incisions do not touch the mid-rib (see Fig. 20.9). When the incision of the lamina goes down to the mid-rib the leaf becomes compound, and then it has a number of leaf-segments. These leaf-segments are known as the leaflets. A leaflet is like a simple leaf but it lacks a bud in its axil. Compound leaves may be of two types (a) *Pinnate* and (b) *Palmate*. A compound leaf is said to be pinnate when the leaflets are lateral to the mid-rib (rachis). When the leaflets are formed by the direct divisions of lamina of the simple leaf, it is *unipinnate* as in rose (see Fig. 20.11c). When the leaflets of the first order again become pinnate, the leaf becomes *bipinnate* (Fig. 20.15a). In this case the actual leaflets are borne laterally on the mid-ribs of the first leaflets as in gold-mohur (*Delonix*), sensitive plant (*Mimosa pudica*). Similarly, a pinnately compound leaf may be *tripinnate* as in *Moringa* (Fig. 20.15b) and *decompound* as in carrot when the number of incisions takes place thrice or more (Fig. 20.15c).

In palmately compound leaves the petiole bears a number of leaflets which resemble a palm. Depending upon the number of leaflets, it may be *unifoliate*, e.g. Lemon, (Fig. 20.16a), bifoliate (not commonly found), *trifoliate*, e.g. Wood apple, *Oxalis*, *quadrifoliate*, e.g. *Marsilea* (Fig. 20.16b) and *multifoliate* (Fig. 20.16c), e.g. *Bombax*, *Cleome*.



20.15 Types of pinnate compound leaf a. Bipinnate b. Tripinnate c. Decompound

Phyllotaxy

Phyllotaxy may be defined as the arrangement of leaves on the stem. It is of three main types:

(1) *Alternate:* Here a single leaf arises at each node in alternate manner. Example: China-rose (Fig. 20.17a).

(2) *Opposite:* In this case, a pair of leaves arises at each node and lie opposite to each other (Fig. 20.17b). Example: Guava, *Calotropis*.

(3) *Whorled:* When more than a pair of leaves are borne at each node, it is whorled, as in *Nerium* (Fig. 20.17c).

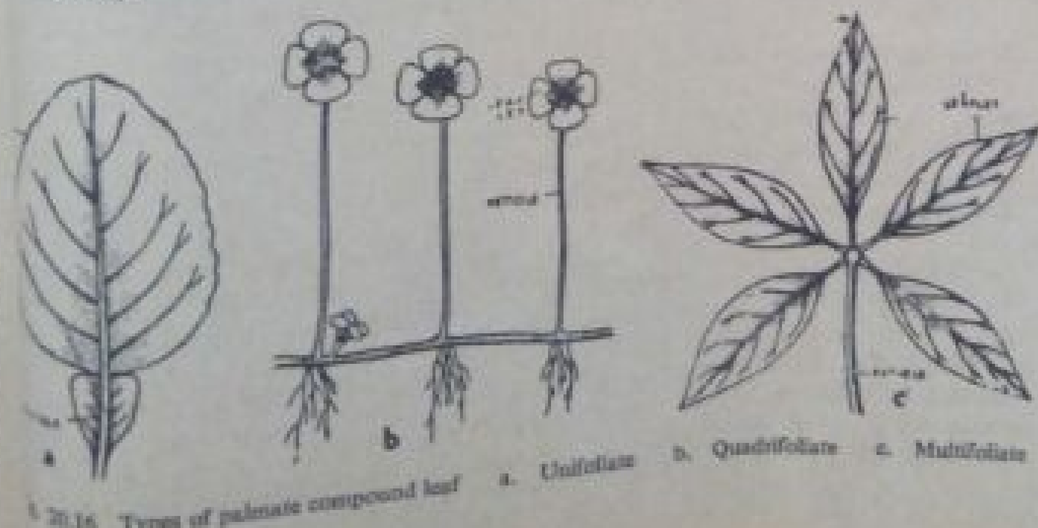
Modification of leaves

Besides their usual function of photosynthesis leaves may be modified to perform other functions as well. Some of the important modifications of leaves are:

(1) *Tendril:* In some plants, the entire leaf or leaflet becomes tendrillar for the purpose of climbing. Example: Pea (Fig. 20.18a).

(2) *Spine:* In a number of plants, leaves become spiny and serve the purpose of defence. Example: *Opuntia* (see Fig. 20.7c).

(3) *Scale leaves:* In onion leaves are in the form of fleshy scales. These are



20.16 Types of palmate compound leaf a. Unifoliate b. Quadrifoliate c. Multifoliate

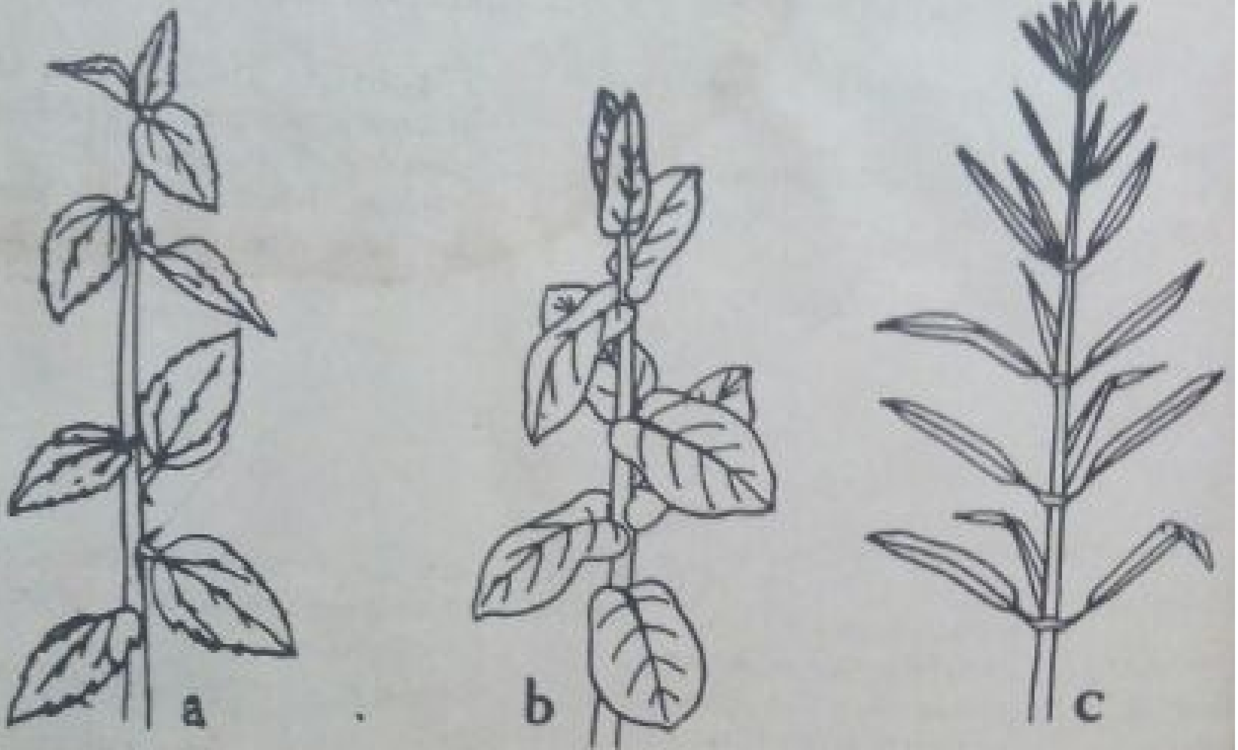


Fig. 20.17 Leaf arrangement on stem a. Alternate b. Opposite c. Whorled

known as scale-leaves. (see Fig. 20.5d).

Pitcher: In some insectivorous plants such as pitcher plant (*Nepenthes*), the lamina assumes the form of a pitcher with a lid to trap the insects (Fig. 20.18b). The inner walls of the pitchers possess a number of digestive glands which secrete a fluid.

(5) *Phyllode:* When the petiole becomes leaflike, it is termed *phyllode*. Example: Australian Acacia (Fig. 20.18c).

EXERCISES

1. Define root. How can you differentiate a tap root from an adventitious root?
2. What do you mean by modifications of root? Describe some of the modifications of tap roots that you have studied, giving suitable examples.
3. What type of modification of roots is found in (a) Sweet potato, (b) *Momordica*, (c) *Asparagus*, (d) *Trapa* and (e) *Cuscuta*?
4. Define annuals, biennials and perennials, giving suitable examples.
5. Describe, giving suitable examples, some of the underground modifications of stem. How can they be distinguished from roots?
6. What types of modification of stems are found in (a) Opuntia (b) *Asparagus*, (c) *Eichhornia*, (d) Mint and (e) Jasmine?
7. Differentiate between phylloclade, cladode and phyllode.
8. Describe the parts of a typical angiospermic leaf.
9. How can you distinguish a simple leaf from a compound leaf? What are the different types of the compound leaf?
10. How do leaves get modified? Describe some of the important modifications of the leaf that you have studied, giving suitable examples.

CHAPTER 21

Reproductive Morphology—Inflorescence, Flower and Fruit

Flowers, which develop from floral buds, constitute the reproductive organs. A flower is a specialized shoot essentially meant for sexual reproduction and has evolved as a result of progressive specialisation of reproductive structures. Formation of fruit is also characteristic of angiosperms.

In angiosperms the reproductive phase sets in only when the vegetative organs of the plant are fully developed. Initiation of this phase is controlled by various factors.

Inflorescence

Inflorescence is the reproductive shoot bearing a number of flowers. It may be terminal or axillary in position. Inflorescence has been classified into two types, viz. *racemose* and *cymose*. Besides, there is also a *special type* of inflorescence which fits into none of these groups.

A. RACEMOSE INFLORESCENCE

In this type of inflorescence the main axis is unlimited in growth, branched or unbranched. It never terminates into a flower and bears flowers in acropetal succession. The main types are:

(1) *Raceme:* The main axis, which is elongated, bears stalked flowers (Fig. 21.1a). Example: Mustard (*Brassica*), Radish (*Raphanus*), Gold-mohur (*Delonix*).

(2) *Spike:* This is like raceme but the flowers are sessile or unstalked. (Fig. 21.1b). Example: *Adhatoda*, Chaff-flower (*Achyranthes*).

(3) *Catkin:* This is like a spike but differs from latter in having a long and pendulous axis, usually bearing unisexual flowers (Fig. 21.1c). Example: **Mulberry,** (*Morus*) Cat's tail (*Acalypha sanderiana*).

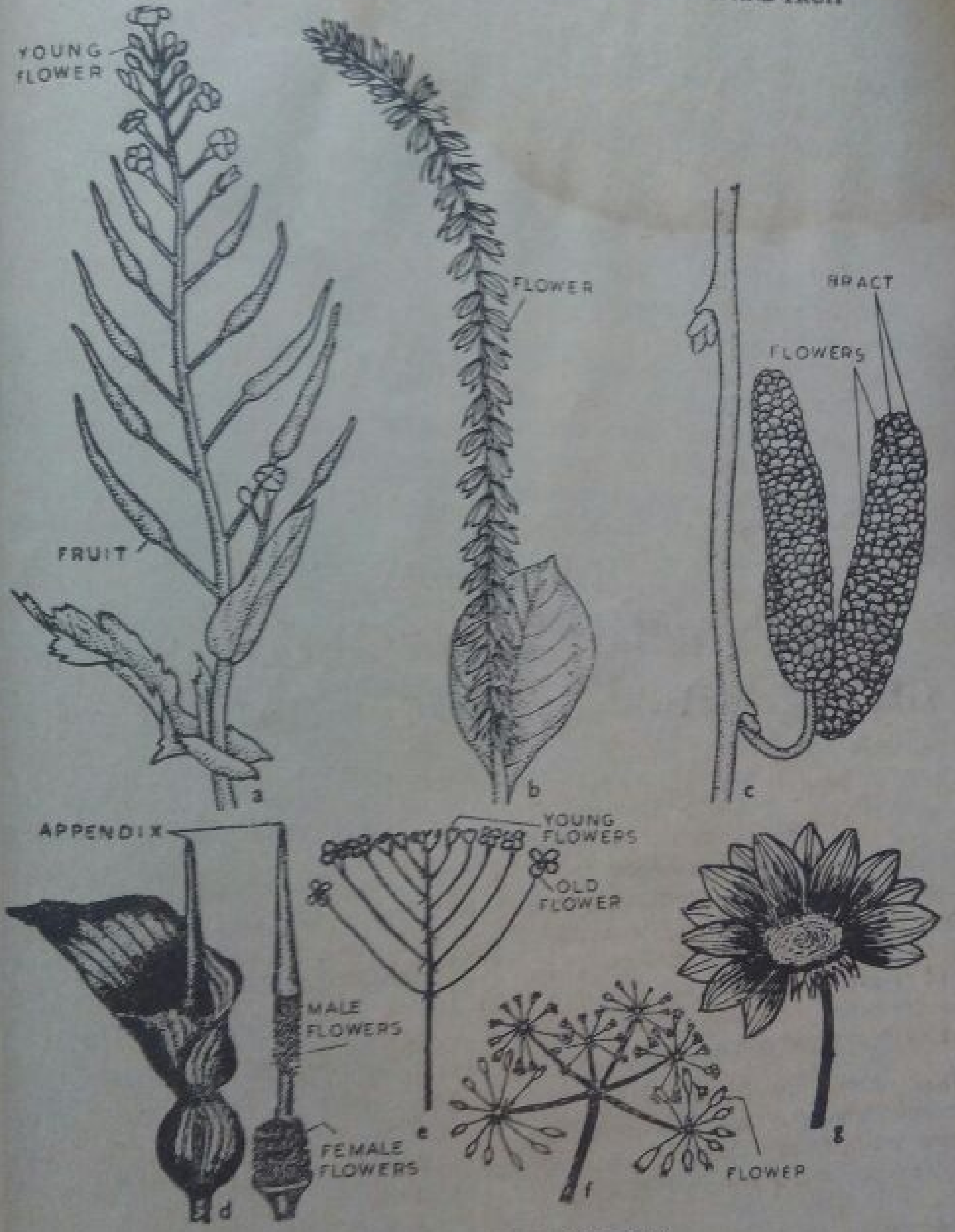


Fig. 21.1. Racemose type of inflorescence
a. Raceme b. Spike c. Catkin d. Spadix e. Corymb f. Umbel g. Head or Capitulum

(4) *Spadix:* This is a spike with fleshy axis enclosed by one or several large and brightly coloured bracts, called the spathes (Fig. 21.1d). Example: Banana (*Musa*), Aroids (*Colocasia*).

(5) *Corymb:* Here the axis is not elongated as in the above mentioned inflorescences. It is short and bears stalked flowers in such a manner that they are placed almost at the same

level (Fig. 21.1e). Example: *Lantana*, Cherry (*Prunus cerasus*).

(6) *Umbel:* This differs from corymb in having a very shortened and suppressed axis. Flowers have stalks of equal length and form a cluster. It is umbrella like in appearance (Fig. 21.1f). Example: (*Hydrocotyle asiatica*), Coriander (*Coriandrum*), Carrot (*Daucas carota*).

(7) *Head or Capitulum:* The main axis is a flattened, more or less convex structure, the receptacle, on which the florets (small-flowers) are arranged in a centripetal order. The whole inflorescence is surrounded by an *involucre* (a whorl of bracts) and bears only one or two types of flowers: inner disc florets and outer ray florets. (Fig. 21.1g). Example: Sunflower.

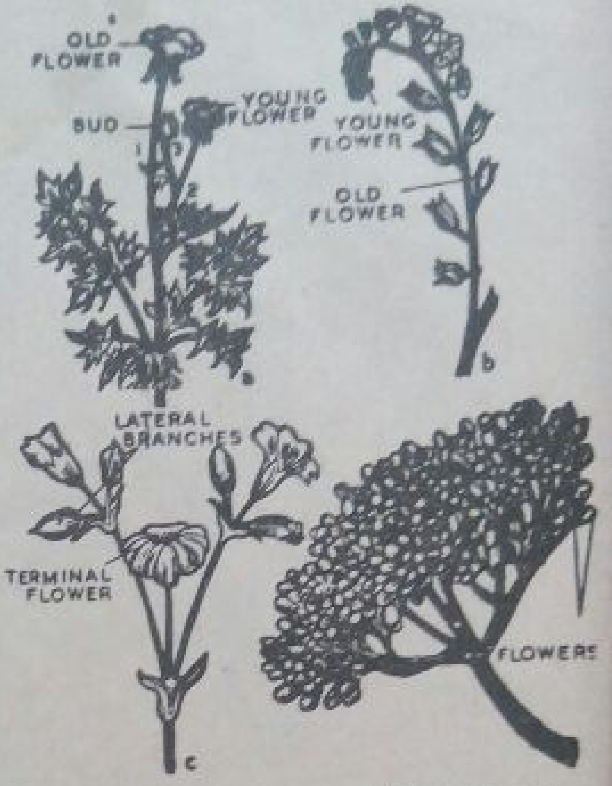


Fig. 21.2 Cymose type of inflorescence
a. Scorpioid b. Helicoid c. Dichasial
d. Polychasial

B. CYMOSE INFLORESCENCE

In this type the main axis is always limited in growth and terminates into a flower. They are usually stalked, and borne in a basipetal order. The main types are:

(1) *Monochasial cyme:* Here the main axis terminates into a flower and one lateral branch axis develops from its base which also ends in a flower. There are two types of monochasial cyme: (a) *Scorpioid type* in which the lateral branches of the axis bearing a terminal flower alternate (Fig. 21.2a) as in *Ranunculus bulbosus*, and (b) *helicoid type* in which each lateral branch bearing a terminal flower develops on the same side forming a helix (Fig. 21.2b) as in *Heliotropium*.

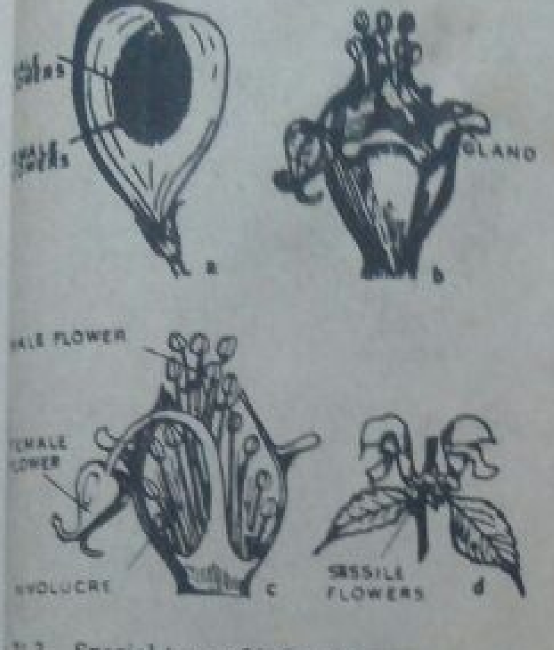
(2) *Dichasial cyme:* Here two lateral branches develop on either side of of the terminal flower (Fig. 21.2c). The lateral branches may again branch similarly. Example: Jasmine (*Jasminum*), Pink (*Dianthus*).

(3) *Polychasial cyme:* Here more than two lateral branches arise from the base of the apical flower (Fig. 21.2d). Example: AK (*Calotropis*).

C. SPECIAL TYPES OF INFLORESCENCES

(1) *Hypanthodium:* Here the main axis forms a cup-shaped receptacle with a small opening at the top. Flowers are enclosed within the cup in cymose groups (Fig. 21.3a). Example: *Ficus*.

(2) *Cyathium:* Here the cup-shaped structure is formed by the involucre. The reduced flowers (without perianth) are placed on a receptacle (Fig. 21.3b). There is one central female flower represented by a single pistil. This is surrounded by a large number of male flowers each represented by a single stamen only. The stalked flowers are subtended by a bracteole. There are also nectar glands on the cup. Example: *Poinsettia*.



21.3. Special type of inflorescence
a. Hypanthodium
b. Cyathium c. Verticillaster

3) *Verticillaster:* Here one inflorescence consisting of two clusters develops from each of the two opposite axils of the leaves (Fig. 21.3c). Each cluster is a dichasial cyme reduced to two scorpioids. Flowers are sessile and appear in a false whorl or *vertically* around the stem. Example: Sacred basil (*Ocimum sanctum*).

wer

The flower is the most conspicuous cture in the angiosperms. It is a highly cialized condensed structure.

rts of a typical flower

The axis of the flower is called the *thalamus* eceptacle). Floral members are arranged spiral or cyclic manner on the thalamus. A ical flower shows four sets of members nged in successive whorls. These are: calyx (2) corolla (3) androecium, and gynaecium or pistil (Fig. 21.4). The first whorls, calyx and corolla, are described non-essential or accessory whorls because y serve secondary functions like protection of flower and attraction of insects for pollination. Androecium and gynaecium are said to constitute the essential whorls because they are meant for reproduction. In some flowers calyx and corolla are undifferentiated and cannot be distinguished. They constitute the perianth.

A flower is termed complete when all the four whorls are present in it, otherwise it is incomplete. When both androecium and gynaecium are present in a flower, it is bisexual or hermaphrodite. A flower lacking either androecium or gynaecium is termed unisexual. Unisexual flowers may be either staminate (male) or pistillate (female). If male and female flowers develop on the same plant, the plant is described as monoecious. If male and female flowers are borne on separate plants, they are termed dioecious. In a number of plants, flowers do not possess sepals and petals. Such flowers are called achlamydeous or naked. Where both calyx and corolla are present, flowers are said to be dichlamydeous. A flower without any functional stamen or carpel is neuter or sterile.

In a typical flower floral members are arranged on the thalamus either in a symmetrical or assymmetrical manner (Fig. 21.5). A flower is termed actinomorphic when its symmetry remains undistrubed if one cuts the flower into two halves through

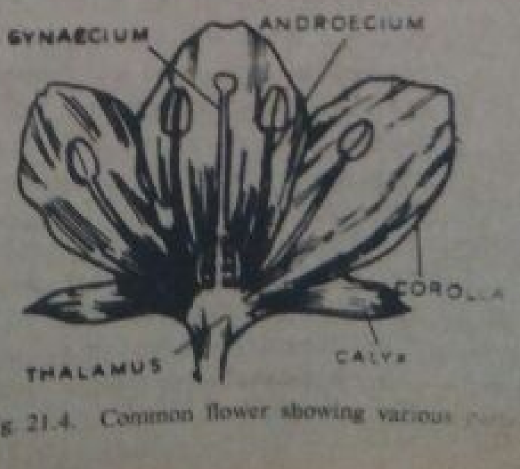


Fig 21.4. Common flower showing various parts

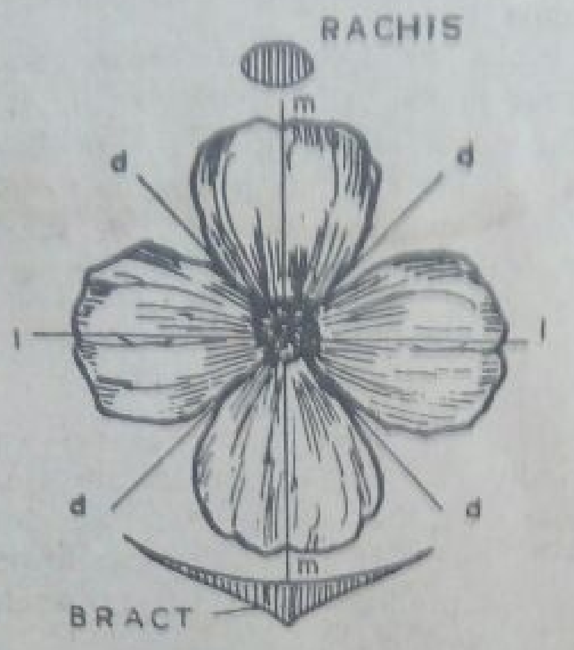


Fig. 21.5. Symmetry plan of a flower.

any vertical plane passing through the axis. Zygomorphic flowers are those where their symmetry remains intact when the flower is cut into two equal halves only through one particular vertical plane passing through the centre.

According to the number of floral members a flower may be trimerous, tetramerous or pentamerous as the number is a multiple of 3, 4 or 5. In monocotyledons, flowers are trimerous whereas in dicotyledons they are tetra-or pentamerous. A typical flower is usually tetracyclic because it has all the four whorls. Flowers may also be polycyclic if the number of whorls increases further.

Thalamus

The thalamus is the suppressed swollen end of the floral axis on which the floral leaves are borne. In some plants, as in passion flower and *Gynandropsis*, it shows distinct nodes and internodes (Fig. 21.6a). The internode between calyx and corolla is termed anthrophore, that between corolla and androecium, the androphore (Fig. 21.6b) and that between androecium and gynaecium, the gynophore (Fig. 21.6c). The shape

Fig. 21.6. Nature of thalamus
a. Androgynophore b. Androphore
c. Gynophore.

Position of floral leaves on the thalamus

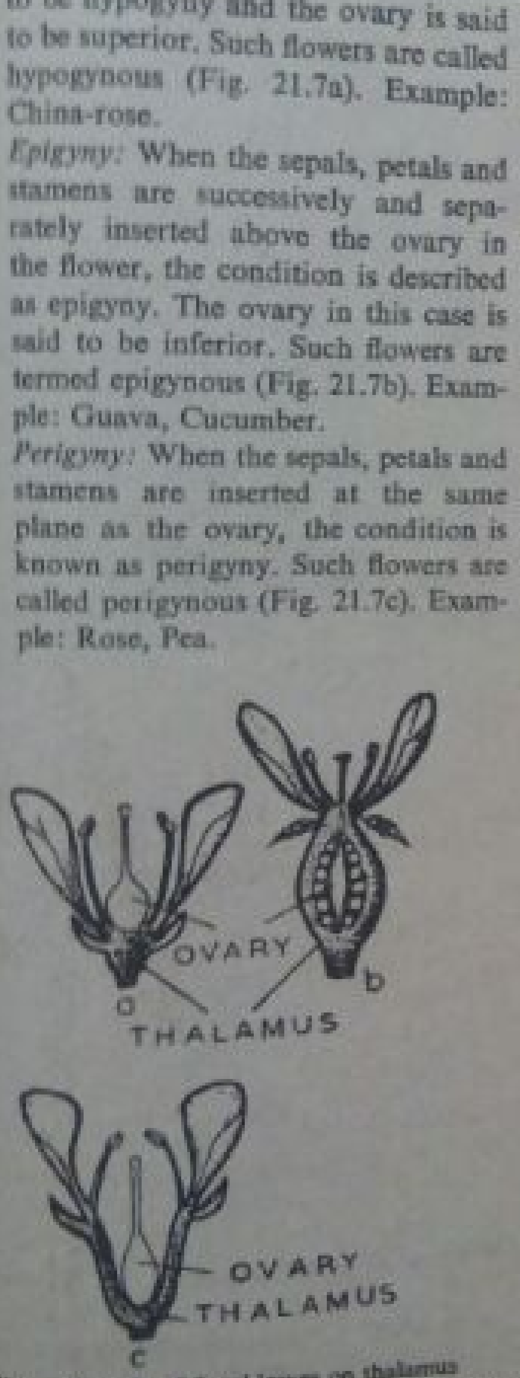
In many flowers the relative positions of calyx, corolla and androecium in respect of

wth of the thalamus. The relative posi- of the floral leaves are of three types:

(1) *Hypogyny:* When the sepals, petals and stamens are successively and separately inserted below the ovary in the flowers, the condition is known to be hypogyny and the ovary is said to be superior. Such flowers are called hypogynous (Fig. 21.7a). Example: China-rose.

(2) *Epigyny:* When the sepals, petals and stamens are successively and separately inserted above the ovary in the flower, the condition is described as epigyny. The ovary in this case is said to be inferior. Such flowers are termed epigynous (Fig. 21.7b). Example: Guava, Cucumber.

(3) *Perigyny:* When the sepals, petals and stamens are inserted at the same plane as the ovary, the condition is known as perigyny. Such flowers are called perigynous (Fig. 21.7c). Example: Rose, Pea.



21.7. Position of floral leaves on thalamus
a. Hypogyny b. Epigyny c. Perigyny

Bracts

Bracts are specialized leaves bearing flower in the axil. Bracts vary in shape, size, colour and duration. A small leafy or scale-like structure present on the floral stalk is known as bracteole. A whorl of bracteoles constitute an epicalyx as in China-rose.

Calyx

It is the lower most accessary whorl consisting of sepals. Sepals are usually green, leaf-like, and protect the flower in the bud stage. The calyx may be polysepalous (with free sepals) or gamosepalous (with united sepals).

Corolla

Corolla is composed of petals. Petals are usually brightly coloured due to the presence of anthocyanin and anthoxanthin pigments in them. Corolla protects the stamens and carpels in the bud condition and attracts insects for the act of pollination. In a petal the lower part is usually narrow like the stalk of a leaf and is termed claw. The expanded portion of the petal is called the limb. Like calyx, corolla may be also polypetalous or gamopetalous. The shape and colour of corolla vary greatly in the plant kingdom. When four free clawed petals are arranged in the form of a cross as in the Cruciferae family, the corolla is said to be cruciform. When petals are united and form a tube like structure as in the disc florets of the Compositae family, it is tubular. On the other hand, ray florets of the same family is tongue shaped or ligulate. In the pea family, five free petals resemble a butterfly hence the corolla is described as papilionaceous. It is differentiated into a large petal (*standard*) two lateral free petals (*wings*) and two inner somewhat united and boat-shaped petal (*keel*). Likewise, corolla may be bell-shaped, funnel-shaped, wheel-shaped, urn-shaped.

Aestivation

Aestivation is the arrangement of sepals or petals with relation to one another in a flower bud. It is of considerable importance in classification of plants. Chief types of aestivation are:

(1) *Valvate*: When sepals or petals in a whorl just touch one another at the margin without overlapping (Fig. 21.8a). Example: *Acacia*.

(2) *Twisted*: When one margin of a sepal or petal overlaps that of the next one and the other margin is overlapped by the preceding one, giving a twisted appearance to the body. Overlapping is in one direction only (Fig. 21.8b). Example: China-rose.

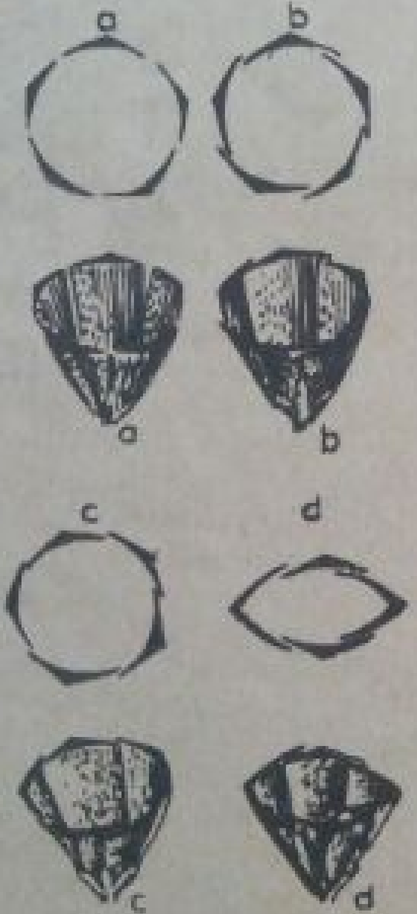


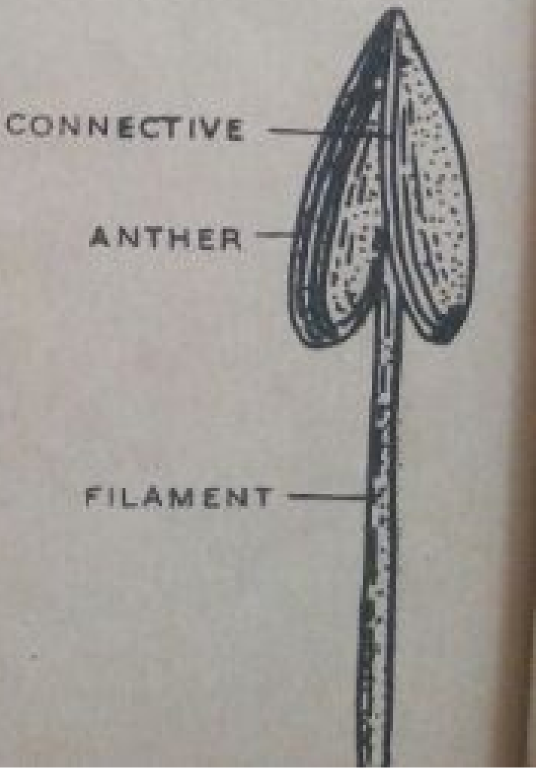
Fig. 21.8 Relation of outer whorls with respect to one another.

(3) *Imbricate*: When the margins of sep or petals overlap one another but not any particular direction (Fig. 21.! Example: Amaltas.

(4) *Vexillary*: This type of aestivation characteristic for the papilionace corolla. Here, the standard overlaps two wings which, in turn, overlaps keel (Fig.21.8d).

Androecium

Androecium is the male sex organ of t plant. It is composed of a number of stame Each stamen consists of a stalk or filame anther and connective (Fig.21.9). In ea anther there are two lobes and each of the has two chambers, the pollen-sacs whi contain pollen grains. A sterile stamen termed *staminode*. When filaments are ve long, stamens protrude out of the flow and are called *exerted*. When stame remain within the flower, they are calle *inserted*.



tachment of the anther to the filament

The mode of attachment of the anther the filament varies greatly in flowers. may be of the following types: (1) *adnate*, hen the filament or the connective is tached to the whole length at the back of r anther (Fig.21.10a), as in *Magnolia* and ater lily: (2) *basifixed*, when the filament is tached to the base of the anther (Fig.21.10b) in mustard (3) *dorsifixed*, when the lament is attached to the dorsal surface f the anther (Fig.21.10c), as the plants of aesalpinioideae, and (4) *versatile*, when e filament is attached to the middle of the nnective so that anther lobes can swing on t freely (Fig.21.10d). The example of this pe is found in most of the grasses.

Stamens in the flower may or may not be f the same length. In mustard, they are *tradynamous* because four stamens of the ner whorl are longer than two in the outer horl (Fig.21.11a). Likewise, it is *didynamous* n *Ocimum* (Fig.21.11b).

nion of stamens

Stamens in a flower may be united in arious ways. When they are united with

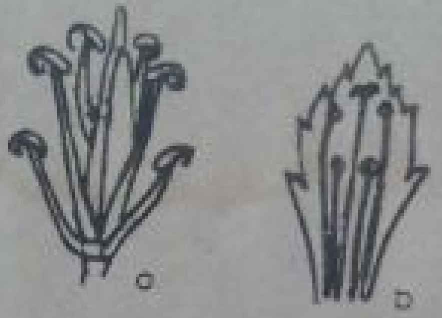


Fig. 21.11. Variations in length of stamen
a. Tetradynamous b. Didynamous

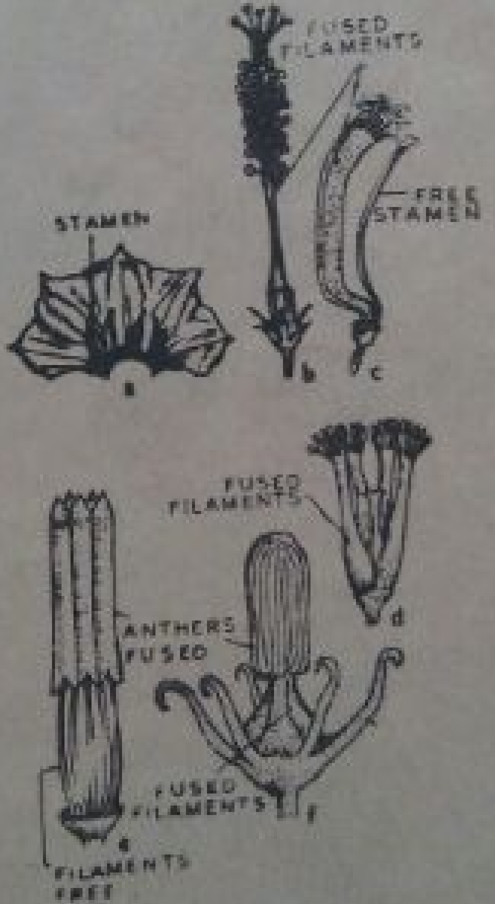
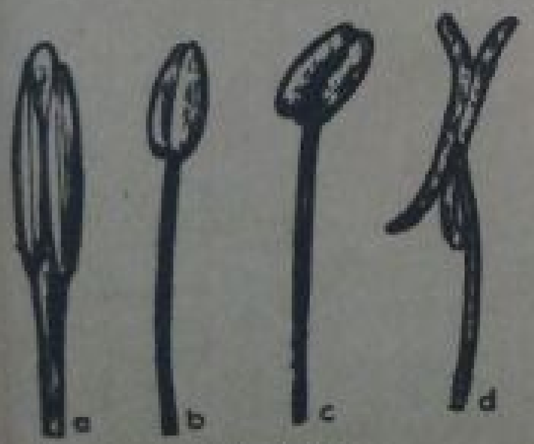


Fig. 21.12. Union of stamens
a. Epipetalous
b. Monoadelphous
c. Diadelphous
d. Polyadelphous
e. Syngenesious
f. Synandrous



g. 21.10. Types of attachment
a. Adnate b. Basifixed
Dorsifixed d. Versatile

other members such as petals or gynaecium, the condition is termed *adhesion*. When they are united among themselves, it is called *cohesion*. When stamens are attached to the petals, they are *epipetalous* (Fig.21.12a), as in brinjal. When all the stamens unite by their filaments and form one bundle, anthers remaining free, it is *monoadelphous* (Fig. 21.12b) as in China-rose. Similarly, stamens may be *diadelphous* pea (Fig.21.12c) and polyadelphous (Fig.21.12d) depending on the number of bundles which they form. An interesting condition exists in the family Compositae. Here, only the anthers of the stamens are fused, leaving the filaments free, which, in turn, are attached to the petals. This condition is termed *syngenesious* (Fig. 21.12e). When both the anthers and the filaments are united, the condition is *synandrous* as in cucurbits (Fig.21.12f).

Gynaecium

The gynaecium or pistil is composed of one or more carpels. When there is a single carpel, the pistil is called *simple* or *monocarpellary*. Similarly, the gynaecium may be bicarpellary and *polycarpellary* if it is composed of two and more

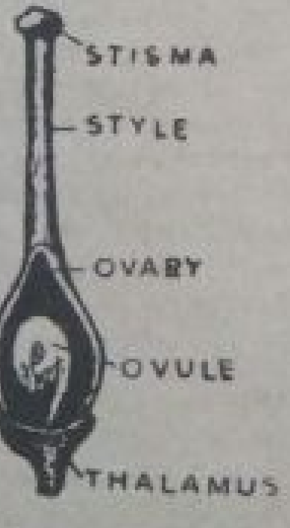


Fig. 21.13. Structure of a typical gynaecium (Carpel).

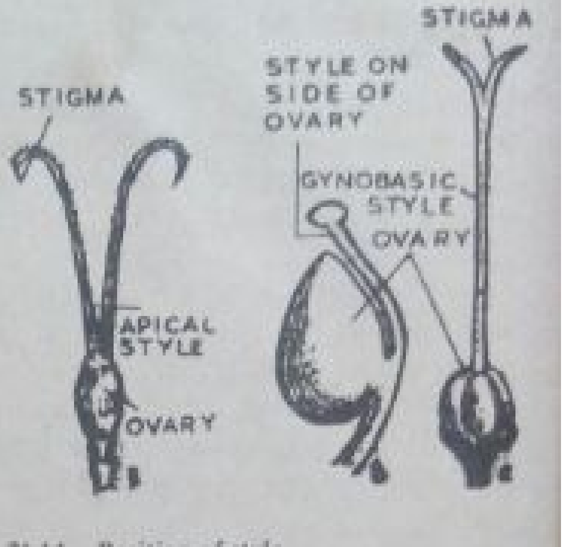


Fig. 21.14. Position of style
a. Apical b. Lateral c. Gynobasic

carpels, respectively. In a polycarpellary pistil, carpels may be free (*apocarpous*) or wholly or partially united, (*syncarpous*). A sterile pistil is known as *pistillode*.

A pistil consists of three parts: **style**, stigma and ovary (Fig.21.13). The style may originate from the apex—apical (Fig.21.14a), from sides—lateral (Fig.21.14b) or from the base (gynobasic) of the gynaecium (Fig. 21.14c). It connects ovary with the stigma. The stigma is usually the tip of the style. It also varies in shape. Ovary is the most important part of the carpel. It contains ovules which develop into seeds after fertilization. The ovary may be *unilocular* (one-chambered) as in Pea or *multilocular* (many chambered) as in the Lady's finger or bhindi. Inside the ovary, the ovules develop from a special tissue, called *placenta*. The manner in which the placentae are distributed in the cavity of the ovary, is known as *placentation*. The following types of placentation are commonly found:

(1) *Marginal:* This is found in leguminous plants. The placenta forms a ridge along the ventral suture of the ovary and the ovules are borne on this ridge forming two rows (Fig.21.15a).

(ii) *Parietal:* Here the placenta is situated at the meeting of two margins of subsequent carpels which may be two or more in number, but one chambered and the ovules are attached to it as in Cruciferae. In cruciferous plants the ovary becomes two-chambered due to the formation of a false septum called the *replum* (Fig.21.15b).

(iii) *Axile:* When the placenta is axial and the ovules are attached to it in a multichambered ovary the placentation is said to be axile, as in the family Solanaceae, Lady's finger, etc. (Fig. 21.15c).

(iv) *Basal.* Here the placenta is situated at the base of the ovary and the ovules are attached to it, as in Compositae (Fig. 21.15d).

The fruit

Fruit is a characteristic feature of the flowering plants. It usually develops after fertilization. But it may also develop without fertilization. Such a fruit is termed *parthenocarpic*. Fruits are of two types: *true* and *false*. A true fruit develops only from the the ovary of the flower while in the development of a false fruit other floral members also participate.

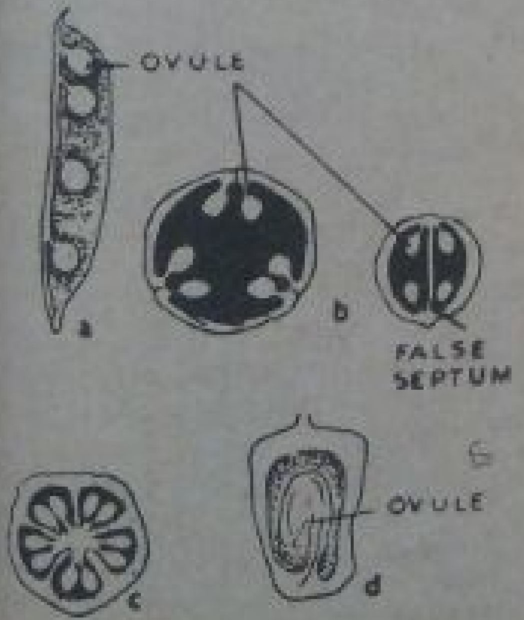


Fig. 21.15. Various types of placentation
a. Marginal b. Parietal
c. Axile d. Basal.

The fruit wall or the pericarp is usually differentiated into three layers—an outer *epicarp*, a middle *mesocarp* and an inner *endocarp*.

Fruits are usually classified into three groups—*simple*, *aggregate* and *multiple*. Simple fruits are further classified into *dehiscent*, *indehiscent* and *fleshy* types. Here we shall describe only the simple fruits.

Dehiscent fruits

Dehiscent fruits burst open automatically on ripening and discharge their seeds. Their mode of dehiscence differs greatly. Dehiscent fruits may be of the following types:

(1) *Legume or pod.* This develops from a superior, monocarpellary, unilocular ovary and is characteristic of the Leguminosae family. The fruit splits along both the sutures (Fig. 21.16a).

(2) *Siliqua.* This develops from a bicarpellary superior ovary and is a characteristic of the Cruciferae family. The dehiscence takes place along both the sutures from base to apex while seeds remain attached to the false partition wall the replum (Fig. 21.16b). *Siliqua* is a short and flattened silicula as in Candytuft (*Iberis*) (Fig. 21.16c).

(3) *Capsule.* This develops from a superior, syncarpous, multilocular ovary and dehisces by means of valves (Fig. 21.16d,e) as in Lady's finger, Cotton, *Datura*.

Indehiscent fruits

Such fruits never dehisce. The pericarp is dry. It may be of the following types:

(1) *Caryopsis:* This type of fruit is a characteristic feature of the grass family. Here the pericarp is fused

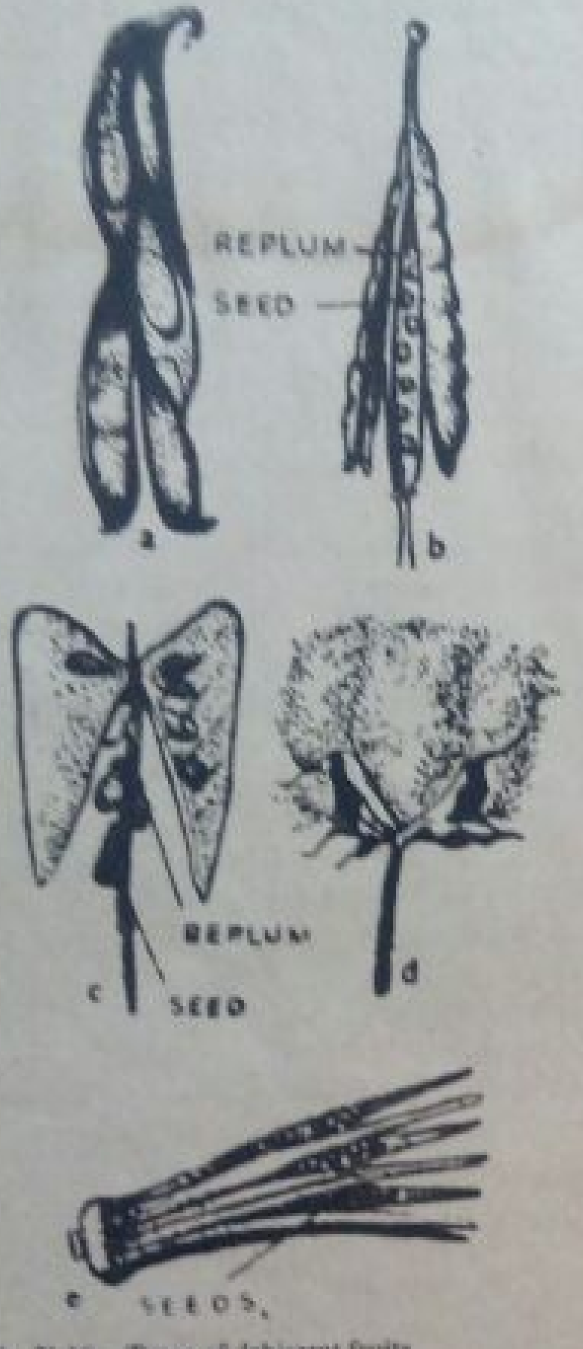


Fig. 21.16. Types of dehiscent fruits
a. Legume b. Siliqua
c. Silicula d. and e. Capsule

with the seed coat (Fig. 21.17a), as in the cereals.

(2) *Cypsela:* This is characteristic of the Compositae. In contrast to caryopsis, the pericarp is free from the seed coat (Fig.21.17b).

(3) *Nut:* This is one-chambered, one-seeded fruit which develops from a superior multicarpellary ovary and has usually a hard and woody pericarp (Fig. 21.17c). Example: Cashew-nut, Litchi (*Nephelium litchi*).

Fig. 21.17. Types of Indehiscent fruit
a. Caryopsis b. Cypsela c. Nut

Fleshy or Edible fruits

Fleshy fruits usually remain succulent and juicy even when fully mature. These are of the following types:

(1) *Drupe:* This is normally one-seeded fruit with its pericarp well-differentiated into an outer skin-like epicarp, a middle fleshy or fibrous mesocarp and an inner stony hard endocarp (Fig. 21.18a). Example: Mango, Coconut, Peach.

(2) *Berry.* This term is applied to any fleshy fruit in which there is no hard part except the seeds. Seeds are embedded in the pulp formed from the various layers of the fruit wall (Fig. 21.18b). Example: Brinjal, Tomato, Banana.

(3) *Pepo:* This is like a berry but develops from an inferior, multicarpellary and syncarpous ovary with parietal

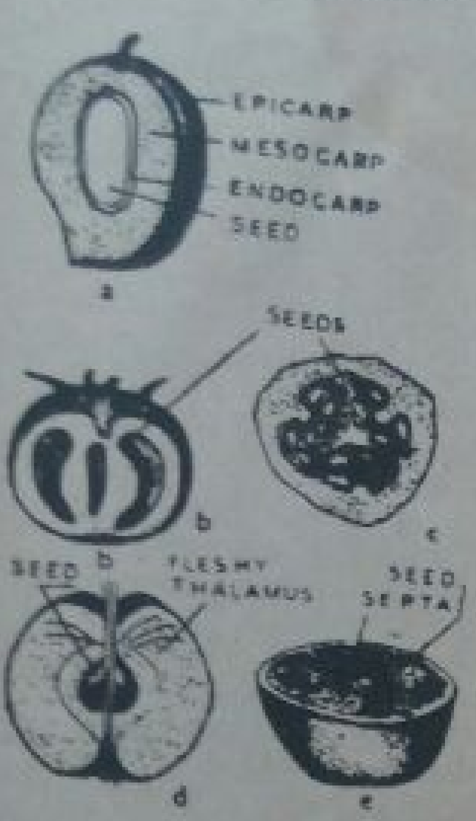


Fig. 21.18. Types of fleshy fruit.
a. Drupe b. Berry c. Pepo
d. Hesperidium e. Pome

placentation as in cucurbits (Fig.21.18c) Example: Cucumber, Water-melon.

(4) *Hesperidium:* This is also like a berry, but it develops from a multicarpellary and syncarpous pistil with axile placentation. Here the epicarp and the mesocarp form a leathery skin,while the endocarp projects inwards forming distinct chambers with juicy hairs (Fig. 21.18d). Example: Orange, Lemon.

(5) *Pome:* This is a false fruit as it is surrounded by a fleshy and edible thalamus (Fig. 21.18e). It develops from an inferior, multicarpellary and syncarpous ovary. Example: Apple, Pear.

Edible Parts of Some Common Indian Fruits

Common Name	Type of Fruit	Edible Parts
Cashew-nut	Nut	Cotyledon and fleshy peduncle
Mango	Drupe	Mesocarp
Cucumber	Pepo	Mesocarp and endocarp
Lady's finger (Bhindi)	Capsule	Whole fruit
Banana	Berry	Mesocarp and endocarp
Coconut	Drupe	Endosperm and embryo
Apple	Pome	Fleshy thalamus
Orange	Hesperidium	Juicy, unicellular hair of the endocarp
Litchi	Nut	Fleshy aril
Tomato	Berry	Whole fruit
Grape	Berry	Pericarp and placenta

EXERCISES

1. What is an inflorescence? What type of inflorescence is found in (*a*) radish, (*b*) gold-mohur, (*c*) aroids, (*d*) coriander, and (*e*) sunflower.
2. Write short notes on (*a*) Cyathium, (*b*) Head, (*c*) Hypanthodium, and (*d*) Corymb.
3. Define a flower. Describe the parts of a typical flower.
4. What do you understand by a hypogynous and epigynous flower? Explain these terms by means of suitable diagrams and examples.
5. What is aestivation? Describe chief types of aestivation in the flower buds that you have studied, giving suitable examples.
6. Please put a tick (√) mark against the correct statement in a box :
   i) A flower is (*a*) a special organ ☐, (*b*) a modified vegetative shoot ☐, (*c*) a branch system ☐ and (*d*) a modified shoot meant for reproduction ☐.
   ii) Aestivation may be defined as (*a*) arrangement of floral leaves in the bud condition ☐, (*b*) attachment of filaments to the anthers ☐, (*c*) arrangement of ovules in the ovary ☐ and (*d*) union of floral parts ☐.
   iii) Placentation means (*a*) union of sepals and petals ☐, (*b*) fixation of anthers to the filament ☐, (*c*) fusion of stamens with the petals ☐ and (*d*) the mode of arrangement of ovules in the ovary ☐.
7. Describe and differentiate syngenesious and synandrous androecium.
8. What is a fruit? Differentiate between true and false fruits?
9. What are edible fruits? Describe chief types of edible fruits that you have studied, giving suitable examples.
10. What types of fruits are found in the following plants: (*a*) Wheat, (*b*) Maize, (*c*) Sunflower, (*d*) Coconut, (*e*) Radish, (*f*) Lady's finger.
11. What constitutes the edible part in the following fruits: (*a*) Cashew-nut, (*b*) Cucumber, (*c*) Mango, (*d*) Apple and (*e*) Orange.

Section III

Systematics

CHAPTER 22

Systematics as a Discipline

A LOOK into the environment reveals a large number of animate and inanimate objects. The animate objects comprise a variety of plants and animals. The enormous abundance and diversity of plants and animals are remarkable. One would naturally feel the necessity of arranging these innumerable living forms in some order. Before starting the study of any organism, it is essential to identify it correctly. Identification, nomenclature and classification are the different sub-divisions of the science of systematics.

Plants and animals were at first classified on the basis of their usefulness and their places of occurrence. As the knowledge of diversity of plants and animals grew, the need for a scientific approach to classification became obvious. From our effort to develop an insight into form and function, origin and development, relationship and adaptation of living organisms, a host of subjects like morphology, anatomy, physiology, embryology, histology, cytology, genetics, ecology, and evolution emerged as definite disciplines. Systematics which deals with the classification or arrangement of different kinds of organisms and the relationship amongst them, also emerged as a distinct discipline of life science.

Origin and Development of Systematics

In a broad sense, systematics is as old as human civilization. Possibly early man not only observed plants and animals, but also named them and tried to classify them.

The written records of classification of organisms in India date back to the time of the Vedas and the Upanishads (1500 B.C. to 600 B.C.). The early Indians recognised oviparous and viviparous animals. Charaka and Susruta, the two eminent ancient Indian scholars and Ayurvedic physicians, contributed in large measure to our knowledge of diversity and utility of organisms.

The early Greek scholars like Hippocrates (460-377 B.C.) and Aristotle (384-322 B.C.) made observations on living organisms and classified them. The most remarkable man in the field of systematics in the 17th Century was John Ray. Before him classification was arbitrary, not based on scientific methods and reasoning. John Ray and Francis Willougby (1635-1672) travelled widely in Europe. They not only observed and collected plants and animals, but also planned to classify them. Unfortunately Willougby died prematurely and later John Ray published his *Historia Generalis Plantarum* in three volumes between 1686 and 1704. In this book, he described accurately and in meticulous detail catalogued over 18,000 plants. Even as early as that, he had the idea of the concept of a species. In his classification, he considered constant and well-defined characters. He, thus, laid the foundation of systematics as a true scientific discipline. Ray's work virtually formed the basis and background for the science of systematics described by the Swedish doctor and botanist, Carolus Linnaeus (1707-1778), who is often referred to, as the father of taxonomy for his outstanding contribution in this field. Linnaeus visited many European countries and made careful observations on plants and animals. He published his scheme of classification in his famous book 'Genera Plantarum' (1737) and 'Species Plantarum' (1757). The 10th Edition of this book published in 1758 and 1st January of that very year marks the beginning of the consistent application of what is known as the "Binomial system of nomenclature". This system which introduces the principles of naming an organism by two words, was first proposed by Linnaeus and is universally followed today.

According to Linnaeus, the species were fixed and immutable. He also believed that all the existing species of animals and plants were the descendants of the previously created species.

Jean Baptiste de Monet Lamarck (1744-1829) was the first to state clearly, that the species change gradually and give rise to new species.

On the basis of extensive study and with the help of convincing evidence, Charles Darwin (1809-1882) propounded his well-known theory of organic evolution. He explained with examples, the origin and evolution of species through natural selection. The Lamarckian and Darwinian theories on evolution not only greatly influenced Linnean classical systematics but also totally rejected the pre-Lamarckian idea of the fixity of species.

Sir Julian Huxley (1940) proposed the term 'New Systematics' to incorporate the results of recent studies in various branches of the life sciences in systematics which modify some of the older ideas of classical systematics. Furthermore, the species is now conceived as a population of individuals and the term 'Population systematics' is now used to cover this new outlook.

Terminology

There are a few terms in systematics which need proper and clear definition.

Systematics: This includes taxonomy, classification, identification, nomenclature, etc. The term 'systematics' is derived from the latinised Greek word *systema*. This word was used by Carolus Linnaeus (1707-1778) in naming his book *Systema Naturae*.

Systematics may be defined as a discipline which deals with the kinds and diversity of all organisms and the existing relationships amongst themselves.

Taxonomy: This term is derived from the Greek words *taxis* meaning arrangement and *nomos* meaning law.

Taxonomy is the study of all plants and imals, their identification and classi-ation.

Classification: Classification may be defi-ed as a system of arrangement of organisms to groups showing relationships.

Identification: Identification is the deter-ination of the correct place or position cupied by an organism in the plan of assification.

Nomenclature: Once an organism is identi-ed it is usually given a name by which it an be referred to.

Nomenclature is the process of giving ientific names to animals and plants. Such nomenclature consists of two words: the rst word is the *generic name* and the second *ecific name*. These words convey definitive formation about the organism. The scienti-c name of a human being is *Homo sapiens*. The word *Homo* means man and the word *apiens* means wise.

Key: A key provides a convenient way for asy identification of an organism using hief distinguishing characters. In a key the haracters are arranged in such a manner hat by selection and elimination one can rrive at the correct identification, of an rganism. The species key will help in the dentification of the species under a genus. he genus key is for identification of different enera in a family.

Utility of Systematics

The study of systematics is important and seful. It gives us an idea of organic iversity, its origin and evolution in the lant and animal kingdoms. The knowledge f systematics is complementary to other ranches of biology such as ecology, enetics, cytology and population biology.

Systematics is also relevant to all sectors f applied biology. India is an agricultural ountry. Systematics is of value in the identi-ication and breeding of a number of eco-nomically important crop plants in our country. Systematics with their expert knowledge can give the correct identity of plants.

Insects are the major pests of our crop plants. They should not only be identified but their habits should also be studied to enable us to devise suitable measures for their control with the help of insecticides (poisons which kill insects). Biological control of insects involves use of other insects as predators and their identification.

In India the problem of epidemic diseases is important. A few species of mosquitoes transmit malaria, filaria, dengue, Kala-azar, etc. The identification of these, their feeding and breeding biology as well as their behavi-our have led to their eradication and control. Thus the systematics of insects has been of use in agriculture and human health. Like-wise, conservation of the beneficial animals requires a knowledge of systematics.

The introduction of harmful plants and animals to a country can be prevented and protected by their correct identification.

Likewise, systematics is of relevance in fisheries, in conservation of natural resources including that of fossils which provide significant clues to resources of oil.

Principles of Classical and New Systematics

The principles of systematics may be divided into two significant eras: (a) Era of Classical Systematics, i.e., from the earliest times to the time of Linnaeus and (b) Era of New Systematics, i.e., post-Linnaean period.

Classical Systematics

The outlook of classical systematics is embodied in the 'typological concept' of species. This concept originated in the philosophies of Plato and Aristotle and was accepted by Linnaeus and his followers. According to this concept, the observed diversity in nature can be reduced or genera-lised into a limited number of types. Indivi-

duals are merely expressions of the same type. The variations observed in the individuals are only imperfect expressions of the type. Furthermore, the species in this concept is a fixed entity and remains static, an idea which is not in keeping with the facts of evolution as we know today.

The concept called 'nominalistic species' indicates that only the individuals have a real existence and that the species are merely conceptual or rather man-made abstractions with no actual existence in nature. Both these concepts have now been abandoned.

The three major systems of classification of organisms proposed by different systematists now well recognised are: (i) artificial, (ii) natural and (iii) phylogenetic.

THE ARTIFICIAL SYSTEM OF CLASSIFICATION

An artificial system of classification is one in which different categories of organisms are recognised on the basis of one or a few superficial resemblances and differences.

This system of classification was adopted by Pliny in the first century A.D., when he classified the animals on the basis of habitats, e.g., land, air and water. Accordingly, the animals were classified into two categories on the basis of their flying ability (a) animals that can fly and (b) animals that cannot fly. In the first group unrelated animals like butterflies, birds and bats were placed together.

The classification of plants on the basis of habit into (a) herbs, (b) undershrubs, (c) shrubs and (d) trees is also an artificial one. The criteria used in this classification, although very simple and easy to follow are arbitrary and do not reflect any natural relationship existing among the organisms. Moreover, it leads to a heterogenous assemblage of unrelated organisms under one heading and does not do justice to the totality of the characteristics of an orga-

The Linnaean system of classification of plants on the basis of number and arrangement of stamens and carpels is also artificial.

THE NATURAL SYSTEM OF CLASSIFICATION

This system of classification unlike the artificial one, avoids the grouping of heterogenous and unrelated organisms.

Botanists and zoologists differ in their interpretation of the implications of this system of classification. According to zoologists, the natural system of classification includes the phylogenetic and evolutionary trends which are evident in the word 'natural'. Botanists hold the opinion, that the natural system does not necessarily include phylogenetic trends of the plants. Here, they proposed the 'phylogenetic system' of classification separate from the 'natural system' to include the evolutionary trends in plants. The 'natural system' of classification of the plant kingdom was proposed by George Bentham (1800-1844) and Joseph Dalton Hooker (1817-1911).

PHYLOGENETIC SYSTEM

In this system proposed by Adolph Engler (1844-1930) and Karl A.E. Prantl and John Hutchinson (1884-1974) plants are arranged and grouped according to their evolutionary sequence.

The Impact of the Doctrine of Descent on Systematics

An analytical study of the various principles of classification shows, that the doctrine of evolution had a great impact upon systematics. It was Charles Darwin who successfully established the truth of evolution. All the pre-Linnaean and Linnaean systems of classification were based on the idea of constancy of species, and thus this idea formed the core of classical systematics. After the acceptance of Darwin's changed concept of evolution, the perspective

systematics totally changed. The concept, species are never static and that they dynamic, became the fundamental out-k of systematics.

Advent of New Systematics

Sir Julian Huxley introduced the very meaningful term 'new systematics'. 'New systematics' aims at taking into considera-n, all the characteristics of organisms gathered from the study of ecology, genetics logy, physiology, biochemistry, behavi-r, etc., for systematics. The classification plants and animals on the basis of chromo-me number has led to the development ...taxonomy. Biochemical characteristics organisms such as the amino acid content d the nature of protein are taken into ...unt under the criteria of classification ...wn as *biochemical systematics*. *Numerical* ...nomy utilises the statistical methods in ...nomy. Similarly, *experimental taxonomy* ...s at identification of evolutionary units ...an species by experimentally determining ...r genetical interrelationship and role of ...ironment in their formation.

Binomial Nomenclature

...menclature concerns the naming of ...s and animals around us. It is essential ...ave common names for plants or animals, ...ever we may be and whatever our own ...uage. This is necessary because the same ...t or animal is known by different local ...es in different countries, States and ...ions. Even in the same locality, the ...le of different languages use different ...l names for the same plant. For ...ple, a certain plant is known as *China-...e* in English, *Gurhal* in Hindi, *Padma-...* in Sanskrit, *Jaba* in Bengali, *Samba-...* in Tamil, *Mandara* in Oriya, *Jaswand* ...rathi. The scientific convention, there-... that all plants and animals shall be ...er Latin or Greek and that the names shall be the same for the people of all languages throughout the world.

Therefore, at present, the nomenclature of plants and animals is done according to a system known as 'Binomial System of Nomenclature'. It was first introduced by Linnaeus. According to this system, the name of a plant or animal is composed of two words in Latin. For example, the scientific name of the mango plant is *Mangifera indica*. It indicates, that the plant belongs to the genus *Mangifera* and to the species *indica*. The first word always denotes the name of the genus and the second of the species. This is the generalised rule in binomial nomenclature. Usually the name of the author, who first describes the species, is also written in full or in an abbreviated form, after the name of the species, e.g., *Mangifera indica* Linn. Here Linn refers to the name of the author, Linnaeus. For animals the names often consist of three parts indicating the generic, specific and sub-specific categories followed by the author's name, e.g., *Columba livia intermedia* Strickland. Such a system of naming is known as trinomial nomenclature.

There are two advantages in the use of scientific names. Firstly, the name of a particular plant or animal is the same scientifically all over the world and secondly, the names are uniformly binomial.

International Code of Botanical and Zoological Nomenclature

"The International Code of Botanical and Zoological Nomenclature" aims at the provision of a stable method of naming taxa, avoiding the use of names, which may cause error, ambiguity or confusion.

The standardisation and legislation of nomenclatural practices are usually made at International Botanical and Zoological Congresses. This is done in order to put the nomenclature of the past in order and to provide guidelines for that of the future.

EXERCISES

1. Discuss the utility of systematics in biology.
2. Who first used the binomial system of nomenclature?
3. What are the advantages of scientific names?
4. Why is an author's name written after the name of the species?
5. How are plants and animals named? Give an example of the scientific name of a common plant and an animal.

CHAPTER 23

Familiarity with Taxa

AXONOMY is based on the principle that atural relationships exist in plants as well s in animals. In classification, plants and imals are placed in categories, that are dicative of such relationships. These categories are species, genera, families, etc. In is way, a hierarchial system of classification built up. This is explained below.

Hierarchy of Categories

Literally 'hierarch' means a series or sucession of different ranks. In biological classification 'hierarchy' is a system of arrangement or a framework for classification in which taxonomic categories are placed in order of logical sequence. It was Linnaeus who, for the first time, established a definite 'Hierarchy' in the animal kingdom. These are *classes, order, genus, species* and *varieties*. Subsequently, categories like phylum (between kingdom and class) and family (between order and genus) were introduced. The category *varieties* was finally discarded or replaced by the sub-species category.

Kingdom	*Animalia*		*Kingdom*	*Plant (After Engler)*	
Phylum	Chordata		Division	Embryophyta siphonogama	
Class	Mammalia		Class	Dicotyledonae	
Order	Primates		Order	Sapindales	
Family	Hominidae		Family	Anacardiaceae	
Genus	*Homo*	Man	Genus	*Mangifera*	Mango
Species	*Sapiens*		Species	*indica*	

The hierarchy of categories (the Linnaean hierarchy) consists of a descending sequence of seven obligatory categories. The categories are given on previous page citing man and mango as examples:

Taxon and Category

Taxon (plural: taxa) is a very usual and extensively used term. In systematics, we are concerned with the groups of organisms, which are concrete objects of biological classification. Thus insects, fishes, birds, algae, fungi, ferns, mosses, grasses, etc., are taxa. For example, the word insects include a group of animals, which have some characteristics in common so that this group may be recognised and assigned a definite taxonomic category in classification. Similarly, fungi include a group of organisms, which may be recognised as a formal unit, since they have some characteristics in common.

A taxon may then be defined, as a unit of classification of organisms which can be recognised and assigned to a definite category at any level of classification.

Category: Plants and animals are ranked in a hierarchy of categories, such as kingdom, phylum (for animals), division (for plants) class, order, family, genus and species. Both in the plant and animal kingdoms, the highest category is the phylum and the lowest, the species.

Taxonomic Categories

Species: The term species occupies a unique position in taxonomic hierarchy. It is not only a basic unit in taxonomy but also in evolution. Although the sub-species, in some cases, has been ranked as the lowest taxonomic category, normally as well as by universal usage, the species is the lowest taxonomic category. *Panthera leo*, the lion, and *Panthera tigris*, the tiger, are species of the genus *Panthera*. *Mangifera indica*, the mango, is a species of the genus, *Mangifera*. However, the most widely accepted definition of species is given below:

A species is a group of individuals of plant or animal, which are genetically distinct, reproductively isolated and similar in morphological characteristics.

Genus: A genus is an assemblage of related species. Obviously, all the species in genus have more features in common than in other closely related groups of species. Further, it is also implied that all the species under one genus have evolved from a common ancestor.

Panthera: It is the generic name for the species representing the lion, the leopard and the tiger. The lion (*Panthera leo*), the leopard (*Panthera pardus*) and the tiger (*Panthera tigris*) have many features in common and they are, therefore, included in one genus.

The genus *Panthera* is differentiated from the related genus *Felis* which includes the golden cat (*Felis temmincki*), the fishing cat (*Felis viverrina*), the leopard cat (*Felis bengalensis*), the marbled cat (*Felis marmorata*) and the jungle cat (*Felis chaus*).

Family: This is a taxonomic category which includes one or more related genera and is separated from other related families by important and characteristic differences.

The lion, the leopard, the tiger and all types of cats belonging to different genera are included under the family Felidae. The family Felidae is distinctly separated from Canidae which includes dogs and foxes.

Order: This category includes related families. Therefore, families like Felidae and Canidae are placed under the order

Class: This category includes the orga-
ms of related orders, e.g., the order Pri-
ites which includes man, monkey, gorilla,
bon, etc., and the order Carnivora which
ludes the lion, the leopard, the tiger, the
, the bear, the dog, etc., are included in
class Mammalia. Besides, there are also
umber of other orders in the class Mam-
lia.

Phylum: Classes of different organisms
ving some features in common are included in a phylum. The phylum Chordata includes a number of classes such as Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia. In the case of the plants, several classes constitute a division, which corresponds to the phylum of the animal kingdom.

Kingdom: This is the highest taxonomic category. All animals are included in the animal kingdom and all plants in the plant kingdom.

EXERCISES

1. Define taxon and category.
2. Indicate the position of man and mango in the hierarchy of main taxonomic categories.
3. Define species.

Genus:- Gp. of related sps which resemble

CHAPTER 24

Outline Classification of the Plant and Animal Kingdoms

In this chapter, the taxonomy of angiosperms is mainly dealt with.

FLORAL FORMULA

When we look at the label on a laboratory reagent bottle, we notice that the chemical formula is written on it. For instance, if it is common salt, the label will bear the formula NaCl meaning, that it is composed of the elements sodium and chlorine. It is a simple formula but it conveys a lot of information to us, so that by looking at it, its chemical nature, properties and uses become clear to us. In the study of plants and floral morphology, abbreviations and symbols are very useful, since they avoid repetition of details of floral description. By convention, these floral details are shown in the form of a diagram and all the floral characters are represented by floral formula. In a floral formula the 'compound' is the flower and the 'elements' are the individual floral parts. In a floral formula the symbols used for the individual floral parts are as follows:

K: calyx, C: corolla, P: perianth, A: androecium and G: gynaecium. The number after each symbol denotes the number of individual members present in a whorl. Thus, $K_5C_5A_\infty G_2$ means, a flower having a calyx of five sepals, a corolla of five petals, an androecium of numerous stamens and a gynaecium of two carpels. In the above example, each whorl is represented by a particular number of individual members occurring in one series. But in some flowers the members of whorl may occur in two or more series. Thus, in *Allium cepa* (onion) the floral formula is written as P_{3+3} A_{3+3} G_3, where the six perianth leaves occur in two series of three each and the six stamens are in two whorls of three each, the gynaecium consists of three carpels.

SYMBOLS SHOWING UNION OR FREEDOM OF FLORAL PARTS

(a) Cohesion, (union between similar members, i.e., sepals with sepals, petals with petals, etc.)—Cohesion of parts is represented by numbers expressed in parenthesis( ). Thus $K_5C_{(5)}\ A_{\infty}G_{(2)}$ means, that the sepals and stamens are free, while the five petals are united with each other just like the two carpels.

(b) Adhesion, (union between dissimilar floral members, i.e., sepals with petals or petals with stamens or stamens with carpels) —Adhesion in a floral formula may be shown either by a line or a bracket connecting the dissimilar members. For example, $K_5\overset{\frown}{C_{(5)}A_{\infty}}G_{(2)}$ means the adhesion is between petals and stamens.

(c) Position of ovary in relation to other floral members—A flower may have a superior or an inferior ovary. In the floral formula a superior ovary is indicated by $\underline{G}$ and an inferior ovary by $\overline{G}$. Thus, for *Hibiscus rosasinensis* (common China-rose), which has a superior ovary, the floral formula is written as $K_5\overset{\frown}{C_5\ A_{\infty}}\underline{G}_{(5)}$. In *Helianthus annuus* (common sunflower) having inferior ovary, the floral formula is $K_{pappus\ oro}\ \overset{\frown}{C_{(5)}A_{(5)}}\ \overline{G}_{(2)}$.

(d) Actinomorphic (regular) and Zygomorphic (irregular) flowers. The following symbols are used for regular and irregular flowers:

$\oplus$ = regular flower (e.g., China-rose); % or

$\oplus$ = irregular flower (e.g., Pea).

These symbols are inserted at the beginning of the floral formula.

(e) Bisexual (both stamens and carpels present) and unisexual (either stamens or carpels present) flowers—When both stamens and carpels are present the flower is said to be bisexual and the symbol ⚥ is used. If one of the essential whorls is missing the flower is unisexual. A unisexual male flower (i.e., when carpel is absent) is denoted by ♂ while a female (with only carpel present but no stamen) by ♀. These symbols are usually placed at the beginning of the floral formula. Thus, the floral formula for common mustard (*Brassica nigra*) is written as $\oplus$ ⚥ $K_{2+2}C_4A_{2+4}G_{(2)}$ and for castor (*Ricinus Communis*) having male and female flowers, the floral formula is as follows:

Male flower $\oplus$ ♂ $P_5A_{\infty}G_0$

Female flower $\oplus$ ♀ $P_5A_0G_3$

If the plant is monoecious (*i.e.*, ♂ and ♀ flowers occur on the same plant) the symbol is ⚥; if it is dioecious (i.e. ♂ and ♀ flowers are borne on separate plants) the symbol is ♂, ♀.

Floral diagram: The above discussion explains that the floral formula is the ground-plan of the flower. But it has many limitations. For instance, it does not tell us anything about the aestivation (arrangement of floral leaves in the bud) of the sepals or petals. It does not reveal the relationship between members of the same or of different whorls. For example, when the sepals occur in two series, an outer and an inner one, the disposition of the floral leaves (sepals) in the outer series may be such that they are either alternate or opposite to those of the inner series or vice versa. Similarly, the sepals may be alternate or opposite to the petals. These features and others, such as the number of chambers in an ovary and its placentation, cannot be shown in a floral formula. However, these can be shown in a floral diagram, which represents a cross-section of the flower. In the construction of a floral diagram, the mother axis i.e., the main axis bearing the flower is shown by a dot outside the floral diagram whereby the terminal or axillary position of the flower also becomes clear. The bract (leaf) in the axil on which the flower is subtended is also shown outside the sepals, petals, etc., usually opposite to the mother axis. In a floral diagram, the sepals form the outermost whorl, followed

by the petals, stamens and carpels. In the case of a perianth no differentiation between sepals and petals is shown. If the floral leaves, are free they show no connections. If cohesion occurs, the individual members of a whorl are connected with each other. Adhesion between members is shown by lines joining the dissimilar members. The floral diagram also shows whether the flower is bracteate (i.e., with bract) or ebracteate (without bract).

The parts of the flower facing the mother axis are anterior, those with their backs towards it are posterior (facing towards the bract). It should be emphasised that for a complete description of a flower and for correct identification, both floral formula and floral diagram are necessary.

Description of Selected Families of Dicotyledons and Monocotyledons

MONOCOTYLEDONEAE

Liliaceae (Fig. 24.1)

HABIT: Perennial herbs with a rhizome or bulb, rarely shrubs or trees (e.g., *Dracaena*, *Yucca*) or climbers (e.g., *Smilax*) STEM: Mostly erect or modified into bulbs (onion), Phylloclade (*Ruscus*), Cladode (*Asparagus*) etc. LEAVES: Radical (occurring in rosettes), cauline, simple, rarely compound, alternate, fleshy or dry and leathery often sharply pointed or reduced to spines, deciduous. INFLORESCENCE: Mostly racemose, sometimes cymose, often solitary. FLOWERS: Bisexual, bracteate, regular or weakly zygomorphic, showy or inconspicuous. PERIANTH: 6 in two whorls of 3, free or united, petaloid or sepaloid may be differentiated into 3 sepals+3 petals, valvate or imbricate. STAMENS: 6 in two whorls of 3, rarely 3, epiphyllous, anthers introrse or extrorse, 2-celled, dehiscence longitudinal or by terminal pores, filaments free or partially united, basifixed or versatile. CARPELS: 3, syncarpous, ovary superior, usually 3-celled with 2 or

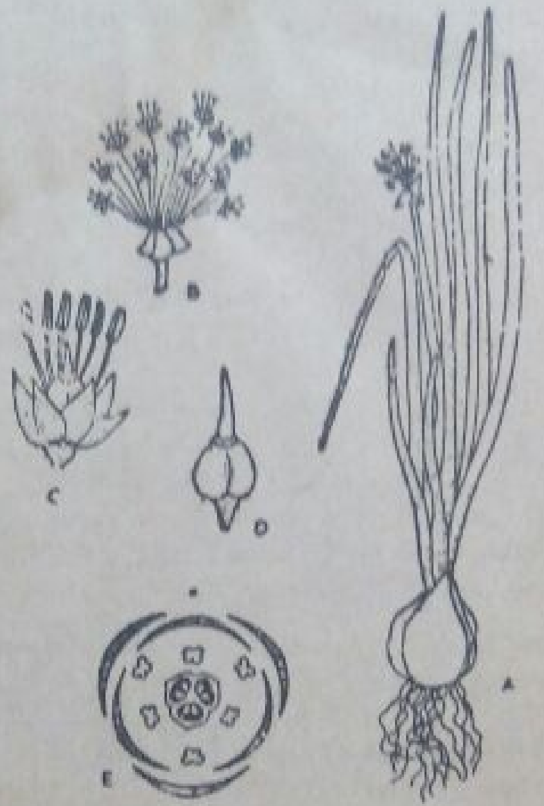


Fig. 24.1. *Allium cepa* (Liliaceae): (A) Plant; (B) Inflorescence; (C) Flower; (D) Pistil; (E) Floral diagram.

more ovules in each chamber, placentation axile, rarely parietal. FRUIT: A berry or capsule. SEEDS: Albuminous.

FLORAL FORMULA: $\oplus$ ⚥ $P_{3+3 \text{ or } (3+3)}\ A_{3+3}\ \underline{G}_{(3)}$

COMMON PLANTS: *Allium cepa* (Onion), *A. sativum* (Garlic); *Asparagus recemosus* (Asparagus); *Smilax macrophylla* (Sarsaparilla); *Yucca gloriosa* (Dagger plant); *Gloriosa superba* (Glory lily).

ECONOMIC IMPORTANCE: *Allium cepa* (Onion) fleshy scale leaves of bulbs, are edible, also those of *A. sativum* (Garlic which is also used against high blood pressure and gout), *Yucca gloriosa* (Dagger plant)— yields fibre; *Colchicum autumnale* and *C. luteum*-drug "colchicine" is obtained from corns, and is used for treatment of gout and rheumatism. It is also used in agriculture as a chemical for inducing doubling of chromosomes (Polyploidy).

uciferae (Fig. 24.2)

ABIT: Annual or biennial or perennial rbs often with pungent watery latex. EM: Erect, solid, herbaceous, branched AVES: Radical or cauline, simple, somees compound, entire or variously incised, ary, alternate, exstipulate. INFLORESCENCE: aceme or corymb. FLOWERS: Bisexual, racteate, regular (irregular in *Iberis*) tetraerous, cyclic, hypogynous, cruciform. IANTH: Differentiated into sepals and tals. SEPALS: 4 i.e, 2+2, free, caducous, bricate. PETALS: 4, free, cruciform with w. STAMENS: 6 i.e., 2+4, tetradynamous outer short, 4 inner long) with glands sent at base of the longer stamens; anrs 2-celled with longitudinal dehiscence. RPELS: 2, syncarpous, sessile, transversely ed, ovary superior, 1-celled first but er becoming falsely bilocular due to the elopment of a false partition or *replum*

24.2. *Brassica nigra* (Cruciferae): (A) Portion of a flowering shoot; (B) Flower; (C) Tetradynamous stamens; (D) Fruit; (E) T.S. of ovary; (F) Floral diagram.

(an outgrowth of the placenta) with many ovules per chamber, Placentation parietal. FRUIT: a siliqua or silicula. SEEDS: numerous, exalbuminous, cotyledons oily.

FLORAL FORMULA: ⊕ ⚥ $K_{2+2}C_4A_{2+4}\underline{G}_{(2)}$.

COMMON PLANTS: *Iberis amara* (Candytuft), *Matthiola incana* (Stock); *Capsella bursa—pastoris* (Shepherd's purse), *Rorippa montana*, *Nasturtium indicum* (Water cress); *Brassica nigra* (Black mustard).

ECONOMIC IMPORTANCE: *Brassica campestris* var. *dichotoma* and *B. juncea*, yield oil from seeds used for cooking; *Brassica oleracea* var. *capitata* (Cabbage); *B. oleracea* var. *botrytis* (Cauliflower); *B. oleracea* var. *gongylodes* (Kohl rabi); *Raphanus sativus* (Radish); are edible vegetables; oil from seeds of *B. campestris* and *B. juncea* are edible.

Leguminosae (Figs. 24.3 to 24.5)

HABIT: Herbs, shrubs or trees, roots with nodules. STEM: Woody as well as herbaceous, erect or climbing, branched. LEAVES: usually compound, rarely simple, stipulate, leaf base often swollen (pulvinus). INFLORESCENCE: Raceme or head or spike. FLOWERS: Bisexual, complete, regular or zygomorphic, hypogynous or slightly perigynous, lateral. SEPALS: 5 or 4, united or free, valvate or imbricate. PETALS: 5 or 4, free or united alternating with sepals, valvate or imbricate. STAMENS: 10 or more, often less by abortion, free or united, diadelphous or monadelphous. CARPEL: One, ovary superior, 1-celled, placentation marginal with many ovules in two alternate rows. FRUIT: A legume or lomentum. SEEDS: Many, exalbuminous.

FLORAL FORMULA: ⊕ ⚥ $K_{4-5 \text{ or } (4-5)}\ C_{4-5 \text{ or } (4-5)}\ A_{10 \text{ or } \infty \text{ or } (10) \text{ or } (9)+1}\ \underline{G}_1$

This family is one of the largest among the angiosperms. Based on the nature of the corolla and stamens, it is sub-divided into three sub-families: (1) Papilionoideae, (2) Caesalpinioideae and (3) Mimosoideae. The

Fig. 24.3. *Pisum sativum* (Leguminosae— Sub-family; papilionoideae): (A) Portion of a flowering shoot; (B) Flower; (C) Diadelphous stamens; (D) Pistil; (E) Petals; (F) Fruit; (G) Fruit split open; (H) Floral diagram.

Fig. 24.5. *Mimosa pudica* (Leguminosae— Sub-family; Mimosoideae); (A) Portion of a flowering shoot; (B) Inflorescence; (C) Flower; (D) Pistil; (E) Fruit; (F) Floral diagram.

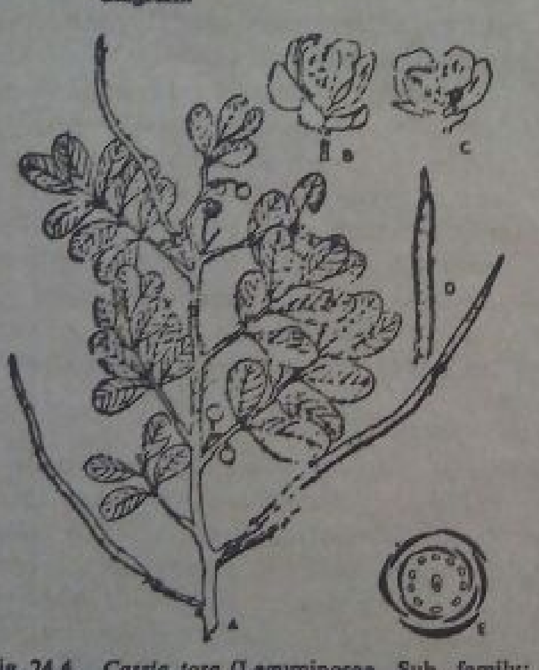


Fig. 24.4. *Cassia tora* (Leguminosae—Sub - family; Caesalpinioideae); (A) Portion of a flowering shoot; (B) Flower; (C) Flower split open; (D) Fruit; (E) Floral diagram.

distinguishing characters of the three sub-families are given below:

(1) *Papilionoideae*: INFLORESCENCE: usually a raceme. FLOWERS: Irregular, (markedly zygomorphic); polypetalous, papilionaceous, with vexillary aestivation with the corolla consisting of 5 free petals, the outermost petal is the largest and forms the standard (Vexillum); the lateral pair also free and forms the wings (Alae), while the 2 innermost are closely appressed forming the keel (Carina). STAMENS: 10, diadelphous (9) + 1, rarely monadelphous 10.

FLORAL FORMULA: %⚥ $K_{(5)}\ C_5 A_{(9)+1} \underline{G}_1$

(2) *Caesalpinioideae*: INFLORESCENCE: Raceme. FLOWERS: Irregular (medianly zygomorphic), polypetalous, with imbricate aestivation. STAMENS: 10 or less by abortion, free or more or less united.

FLORAL FORMULA: %⚥$K_5\ C_5\ A_{10}\ \underline{G}_1$

(3) *Mimosoideae*: INFLORESCENCE: A head or a spike. FLOWERS: Regular, valvate

estivation. SEPALS: More or less united below into a cup. PETALS: may also be united at base, valvate. STAMENS: numerous or 10 or 8 or 4, free, or united at the base; anthers 2-celled, dehiscence longitudinal.

FLORAL FORMULA: $\oplus ⚥ K_{(5-4)} C_{(5-4)} A_{\infty, 10, 8 \text{ or } 4} \underline{G}_1$

COMMON PLANTS: (1) *Papilionoideae*. *Erythrina indica* (Coral tree); *Clitoria ternatea* (Butterfly pea); *Crotalaria retusa* (Rattle wort); *Butea monosperma* (Flame of the forest); *Lathyrus odoratus* (Sweet pea).

(2) *Caesalpinioideae*: *Cassia fistula* (Indian laburnum); *Tamarindus indica* (Tamarind); *Delonix regia* (Goldmohur); *Saraca indica* (Ashoke); *Bauhinia acuminata* (Camel's foot); *Caesalpinia bonducella* (Fever nut).

(3) *Mimosoideae*: *Mimosa pudica* (Sensitive plant); *Samanea saman* (Indian rain tree); *Inga dulcis* (Manila tamarind); *Acacia moniliformis* (Australian acacia); *A. arabica* (Gum tree); *Adenanthera pavonina* (Red wood).

PLANTS OF ECONOMIC IMPORTANCE: (1) *Papilionoideae*— The important pulses of the subfamily are: *Pisum sativum* (Pea); *Phaseolus mungo* (Black gram); *Cajanus cajan* (Pigeon pea); *Dolichos lab-lab* (Black bean); *Vigna catjang* (Cow pea); *Crotalaria juncea* (Sun hemp)—stem fibres are used for making ropes, mats, paper etc., *Dalbergia sissoo* (Indian Rosewood); *Pterocarpus marsupium* (Indian kino) are lumber-yielding; *Indigofera tinctoria* (Indigo—the leaves of this plant yield indigo a dye, but it does not come directly from the plant; the leaves contain a chemical compound which is colourless but on exposure to air becomes oxidised and yields the blue-dye, indigo); *Arachis hypogea* (Groundnut) seeds are edible and yield groundnut oil which is also edible and used for cooking and also in the manufacture of soaps and toilet products; *Abrus precatorious*—a climber, has red coloured seeds, which are used as jeweller's weights; *Aeschynomene aspera* (Indian cork)—yields cork; *Glycyrrhiza glabra* (Indian liquorice)—dried roots, yield liquorice, used as an expectorant and also to disguise the tastes of nauseous preparations; it flavours tobacco and candy and is used in the manufacture of shoe polish; 'glycyrrhizin' is a solution for etching steel sections in photomicrographic work.

(2) Caesalpinioideae: *Cassia angustifolia* (Senna) dried leaflets and pods yield Senna which is used as a purgative; *Saraca indica*—The decoction from the bark is used as a medicine against female diseases; *Haematoxylon campechianum* (Logwood) a native of Central America and West Indies; heartwood yields haematoxylin, a stain used in microscopic studies of cells; *Tamarindus indica*—fruit is edible, pulp of fruit is the source of tartaric acid; *Caesalpinia echinata* (Brazil wood)—red dye from bark and pods used for colouring cotton and woollen cloth and for red ink; the wood is valuable material for violin bows; *C. sappan* (Sappan wood)—heartwood also yields red dye.

(3) *Mimosoideae*: *Acacia arabica*—yields 'gum', *A. catechu* (Cutch)—the gum yields astringent known as "Khair" which is used as a dressing with betel leaf; it is also used against tooth decay; the resinous extract from the heartwood (Cutch) is also used in the tanning and dyeing industries; *Xylia xylocarpa*-yields timber for the construction of railway sleepers and ships.

Solanaceae (Fig. 24.6)

HABIT: Herbs, shrubs or small trees (e.g. (*Solanum verbascifolium*) very rarely climbers (e.g., *Solanum jasminoides*). STEM: Usually herbaceous, erect, solid and branched. LEAVES: Simple, entire or variously lobed or pinnately compound, alternate or opposite, exstipulate, surface hairy. INFLORESCENCE: Solitary or in simple or panicled cymes. FLOWERS: Bisexual, regular, gamopetalous; hypogynous, penta-

Fig. 24.6. *Solanum nigrum* (Solanaceae); (A) Portion of a flowering shoot; (B) Flower; (C) Flower cut open; (D) Fruit; (E) T.S. of ovary; (F) Floral diagram.

merous. SEPALS: 5, united, imbricate, persistent often enlarging in the fruit (e.g., *Physalis peruviana*). PETALS: 5, united, forming a rotate or funnel-shaped or bell-shaped corolla, rarely bilabiate (e.g., *Shizanthus*); imbricate or plicate (folded). STAMENS: 5, epipetalous, inserted within corolla tube or alternating with corolla lobes: anthers 2-celled, with porous or longitudinal dehiscence; hypogynous disc is obvious. CARPELS: 2, syncarpous, obliquely placed, ovary superior, usually 2-chambered or falsely 3-5 chambered with many ovules per chamber; placentation axile; style simple, terminal, stigma capitate, bilobed. FRUIT: A many seeded berry (e.g., Tomato) or capsule (e.g., *Datura*). SEEDS: Many, more or less uniform albuminous, embryo curved, sometimes straight.

FLORAL FORMULA: ⊕⚥ $\widehat{K_{(5)}\, C_{(5)}}\, A_5\, \underline{G}_{(2)}$.

COMMON PLANTS: *Solanum nigrum* (Black night shade); *S. melongena* (Brinjal or egg plant); *S. tuberosum* (Potato); *Brunfelsia* (*Francisia*) *hopeana* (a Brazilian plant popularly known as "yesterday, today, tomorrow" is commonly seen in the gardens); *Cestrum nocturnum* (Night jasmine); *Nicotiana*; *plumbaganifolia* (Wild tobacco). ECONOMIC PLANTS: Potato (stem tuber, brinjal (berry-fruit), tomato (*Lycopersicon esculentum*--berry); Chillies (*Capsicum frutescens*—also fruit used as vegetables. Chillies are also used as spice or condiment; *Nicotiana tobacum* (Tobacco plant)—leaves yield narcotics; *Atropa belladona* (Deadly nightshade)—dried leaves stems and roots yield 'belladona' to relieve pain, cough and excessive perspiration; Atropine is a drug obtained from the same plant from dried leaves, to dilate the pupil of the eye; *Datura metal* and *D. stramonium* (Jimson weeds)--roots and dried leaves used for the treatment of asthma; *Physalis peruviana* (Cape gooseberry)—fruits edible (concealed within enlarged sepals).

Compositae (Fig.24.7)

HABIT: Herbs, shrubs or rarely trees (e.g., *Senecio*), or may be climbers (e.g., *Mikania scandens*); the sap sometimes milky (e.g., *Eupatorium*). STEM: Usually herbaceous, erect or prostrate, solid and hairy. LEAVES: Simple, alternate, sometimes opposite or whorled, exstipulate. INFLORESCENCE: *Capitulum* with a few to many flowers or of 1-flower, with involucre of bracts. The capitulum may be homogamous (with similar type of flowers as in *Mikania*) or heterogamous (with two types of flowers— the outer ray and the inner disc florets as in sunflower); the receptacle may be of various shapes and forms. FLOWERS: Bisexual or unisexual, monoecious or dioecious, or neuter, regular, epigynous, bracteate or ebracteate; bracts chaffy or scarious, deciduous or persistent.

RAY OR MARGINAL FLORETS: Unisexual and female or neuter, zygomorphic, epigynous, ligulate (strap shaped). SEPALS: modified into a hairy pappus in a ring or bristle like, sometimes scaly or absent. PETALS: 5, united,

Fig. 24.7. *Helianthus annuus* (Compositae): (A) Portion of a flowering shoot; (B) Inflorescence; (C) Disc floret; (D) Ray floret; (E) Anthers (syngenesious); (F) Floral diagram.

zygomorphic often bilabiate, usually ligulate, valvate. STAMENS: absent. CARPELS: 2, syncarpous, ovary inferior, 1-chambered with basal placentation; style-simple, 1, stigma bifid. FRUIT: a cypsela.

FLORAL FORMULA: % ♀ $K_{pappus}\ C_{(5)}\ A_0\ \overline{G}_{(2)}$

DISC FLORETS: Bisexual, regular, tubular, epigynous, SEPALS: As in ray florets. PETALS: 5, gamopetalous, tubular. STAMENS: 5, epipetalous, syngenesious (filaments free, anthers united, often forming a tube around the style, introrse, anthers 2-celled, dehiscence longitudinal. CARPELS: As in ray florets. FRUIT: as in ray florets. SEEDS: 1, exalbuminous. FLORAL FORMULA: ⊕ or ① ⚥ or ♀ or ♂

$K_{pappus\ or\ 0}\ \widehat{C_{(5)}A_{5\ or\ 0}}\ \overline{G}_{(2)\ or\ 0}$

COMMON PLANTS: *Tagetes patula* (Marigold); *Zinnia elegans* (Zinnia); *Lactuca sativa* (Lettuce); *Mikania scandens* (Climbing hemp weed); *Vernonia cinerea* (Iron weed); *Elephantopus* scaber (Elephant's foot).

ECONOMIC IMPORTANCE: *Helianthus annuus* (Sunflower)—seeds yield edible oil; *H. tuberosus* (Jerusalem artichoke)—root tubers edible; *Carthamus tinctorius* (Safflower)--petals yield an orange dye. Safflower oil is obtained from the seeds for the manufacture of soap, dye, varnish; the oil is also edible; *Artemisia vulgaris* and *A. maritima*, flowers yield Santonine a drug used for curing intestinal worms: *Chrysanthemum coccineum* (Chrysanthemum—roots yield Pyrethrum an insecticide; *Enhydra fluctuans* (Water cress) —leaves used as vegetable also cure insomnia (sleeplessness); *Eclipta alba* (Keshut) leaves used as hair tonic; also *Wedelia calendulacea* (Bhringaraj of Ayurveda)—leaves used as hair tonic.

ANIMAL KINGDOM

On this earth, nearly one million types of animals are known. Some animals may be *solitary* and some may live in groups. The extreme cases of collective living are seen in the forms which live as *Colonies*. Some animals live an independent life and are called *free-living*. There are others which live in various types of associations. The association is called *parasitism* when one individual (*Parasite*) lives at the expense of the other (*host*). When two individuals mutually benefit each other, the association is called *symbiosis*. There are associations, when two members neither benefit nor harm each other. This is called *commensalism*.

All animal types have different *habitats* and diverse characters, which are expressed through *shape, size, symmetry, segmentation, appendage, skeleton, sex, embryonic development, larval forms* and *features of the internal organs*. In order to find out these characters in different animals, we must know, what these characters mean.

Habitat

Some animals live in water. They are called *aquatic* animals. Some live on land and are known as *terrestrial* animals. The terrestrial animals may live underground, above the ground or on the branches of the trees. Some forms can fly in air and are called *aerial*.

The aquatic forms living in seas are called *marine* and those which live in rivers, lakes and ponds are called *fresh water* forms. The aquatic forms may be free swimming called *pelagic*; those forms which remain attached to stones or some under water objects are called *benthos*. Some aquatic forms cannot swim actively but are drifted passively by water currents. They are called *planktons*.

Shape and Size

The shape of the animals depends upon its way of life. Animals which are adapted for swimming and flying have spindle shaped body. The animals which are good runners also have streamlined shape. The part of the body which is away from the ground is called *dorsal*, the part which is towards the ground is called *ventral*. The two sides are called *laterals*. The end which usually moves forward and bears the mouth is called *anterior* and its opposite side usually bearing the anus is called *posterior*.

The size of animals also varies widely. Some animals are microscopic and in many of them the body is made up of a single cell. They are called *unicellular* animals or protozoa. In *multicellular* animals, the body is made up of many cells. They are also known as *metazoa*. In metazoa, the cells may be arranged in two layers. They are described as *diploblastic*. In others, when the cells are arranged in three primary layers, they are called *triploblastic*.

Symmetry

An animal body can be divided either along the *transverse* plane or along the *longitudinal* plane. The symmetry is the plan of arrangement of the constituent parts of the body. In some cases, the arrangement is such that the organism is divisible into similar halves through one plane only. This is called *Bilateral symmetry*. But in animals, where it is possible to get two similar halves by any one of many longitudinal planes passing through the centre, it is called *radial symmetry*. In some animals, it is not possible to divide into two similar halves. They are called *assymetrical*.

Segmentation

In a large number of multicellular animals, the body is divided into a row of similar compartments called metameres or segments. The partition wall of these segments may divide the body externally as well as internally. Such segmentation is called *metameric segmentation*. Each metameric segment usually has a pair of appendages. In some animals, segmentation is apparent only in embryos, but in adults these segments fuse and specialise to form distinct regions like *head*, *neck*, *thorax*, *abdomen* and *tail*. Many animals of course have unsegmented body.

Appendage

The appendages are present externally in the body of animals as elongated structures used for locomotion and other functions. The appendages may be *paired*, i.e. one on each side or *unpaired*. The appendages which are meant for locomotion may be modified for various types of movement, i.e., swimming, climbing or flying.

Skeleton

Skeletons are hard structures for providing support and protection to the body. Animals without skeleton are called *soft bodied*. Sometimes the skeleton is found inside

body and is called *endoskeleton* and when side the body, it is called *exoskeleton*. e exoskeléton is formed by the deposition dead materials but endoskeleton in most imals is supplied with blood vessels and rves and is called living skeleton.

x

In some animal groups there are no ference of sex. They are called *asexual*. t in most animal types there are sex differences—some are *males* and some are *females*. hose individuals are called *unisexual*. The o sexes are usually characterised by their nads—testis and ovary respectively. There some other characters of the body which associated with the sex of an individual. In me animal forms both the sex organs (male d female) are located in the body of one dividual. Such animals are called *herma-phrodities* or *bisexual*.

bryo and larval forms

In sexually reproducing forms, some imals release reproductive cells outside the dy. In such forms reproduction is called *ternal*. But in other forms, there are specialed structures in males for depositing reproductive cells inside the body of the female. ich reproduction is *internal*. In the forms ving external reproduction, development also external. But in internally reproducing rms, in some, development of the embryo kes place internally and in others development of the embryo occurs outside the body. he animals which lay eggs are called *ovipar-* and which give birth to young ones are lled *viviparous*. In certain forms, the newly tched or newly born young resembles e adult. In such case, the development is lled *direct*. But in many animals, the young es do not resemble the adult. These young es are called *larvae*. The larvae leads dependent life for a certain period and pass rough several stages and finally become adults. This transformation is called *metamorphosis* and kind of development is called *indirect* development.

Internal organisation

Animals which are triploblastic, have three layers of cells in the body wall—outer *ectoderm*, middle *mesoderm* and inner *endoderm*. In some animals the mesoderm splits to form an internal cavity called *coelom*. The coelom is thus lined on all sides by mesoderm. The animals where coelom is present, are called *coelomate* and animals without coelom are known as *acoelomate*. In some animal forms the space, within mesoderm carry blood and are called *haemocoel*.

Animals which are parasites may not have well developed organ systems. Various types of food getting or food capturing devices are seen in the animal world. For example, pseudopodia in Amoeba, tentacles in hydra, suckers in leeches, mouth parts in insects, tongues in frogs, beaks in birds and fore limbs in monkeys and men.

The respiration and excretion are the two vital activities, for which innumerable variety of structures are seen. For example, the aquatic forms respire either through *skin* (cutaneous) or through specialised structures called *gills*. The gills may be present outside the body (external gills) or inside the body (internal gills).

The air breathing animals have lungs as respiratory organs and the respiration is called *pulmonary respiration*. In flying birds, lungs are associated with specialised thin walled, elastic bags called *air sacs*.

The excretory organs are also of various types. In unicellar forms, there are special vacuoles called *contractile vacuoles*. In many animals, the skin which is periodically replaced (ecdysis) also removes some waste products. In animals like earthworm and leeches, each segment bears a pair of whitish tube called *nephridia*. In higher forms like the vertebrates function of excretion is carried

out by a special organ called the kidney. Besides, these there are several other organs in different animals, which perform the function of excretion. For example, *Malpighian tubules* in insects, *antennary glands* in *prawn*.

In most animals, there is a circulatory fluid called *blood*, which flows through *blood vessels*. In animals, where blood vessels open in the coelomic space, the circulatory system is called *open type*. Where blood always flows through definite vessels, the circulation is called *closed type*. In animals like mammals and birds, the body temperature does not change with the change of external temperature. They are called *warm blooded* or *homiothermal*. But in most animals the body temperature changes with the change in environmental temperature. They are called *cold-blooded* or *poikilothermal* animals.

The cold blooded animals cannot remain active during winter. They remain inactive during this period and the process is called as *hibernation*.

1. Phylum Protozoa (Fig. 24.8)

Salient features:—

1) Microscopic, single-celled; (with one or more nuclei).
2) Solitary or colonial; free living or parasitic or symbiotic
3) Locomotion by contractile movement of the cell, or by special locomotory structures called pseudopodia, flagella or cilia
4) Mode of nutrition-holophytic (manufacture food like green plants), holozoic (eat other plants and animals), saprophytic (obtain nutrients from dead, decaying organisms) or parasitic.
5) Reproduction commonly by fission.

Fig. 24.8. Examples of Protozoa (diagrammatic): (A) *Amoeba*; (B) *Entamoeba*; (C) *Noctiluca*; (D) *Nectotherus*; (E) *Euglena*; (F) *Paramoecium*; (G) *Vorticella*; (H) *Trypanosoma*.

I. SUB-PHYLUM—SARCOMASTIGOPHORA

Salient features—

1) Locomotory structures are flagella or pseudopodia.
2) No spore formation.

Sarcomastigophora is divided into the following classes—

Class Phytomastigophorea:— e.g. *Euglena*, *Volvox*

1) Usually possess a pigment containing bodies called chromatophores which may be secondarily lost.
2) Presence of one or two flagella.

Class Zoomastigophorea: e.g. *Trichomnas*, *Trypanosoma*.

Salient features:—

1) Usually live in association with other animals.
2) Presence of one or many flagella.
3) Chromatophores are absent.

Class Rhizopodea: e.g., *Amoeba*, *Entamoeba*

Salient features—

1) Nutrition is holozoic
2) Locomotion is by pseudopodia.

There are two other classes *Piroplasmea* (e.g. *Babesia*) and *Actinopodea* (e.g. *Pinettea*)

SUB-PHYLUM SPOROZOA

Salient features—

1) Simple spores

2) Cilia absent, but flagellated gametes may occur, Sub-phylum sporozoa is divided into following classes:

Class Telosporea: e.g. *Monocystis, Plasmodium* (malarial parasite)

Salient features—

1) Spores present but produced at the end of the life of trophozoite and no capsule or filament.

2) Locomotion by gliding or body flexion.

There are two other classes Toxoplasmea e.g. *Toxoplasma*) and Haplosporea (e.g. *Haplosporidium*).

III. SUB-PHYLUM CNIDOSPORA

Salient features—

1) All are parasitic

2) Presence of spores having one or more filaments. Spores with one to four polar capsules, with a coiled polar filament.

The sub-phylum includes two classes—Myxosporidea (e.g. Myxidium) and Microsporidea (e.g. *Nosema*).

IV. SUB-PHYLUM CILIOPHORA

Salient features—

1) Presence of Cilia

Sub phylum Ciliophora has only one class Ciliata.

Class Ciliata e.g. *Paramoecium, Vorticella.*

Salient features—

1) Free living forms with cilia.

2) Usually two types of nuclei are seen.

2. **Phylum Porifera** (Fig. 24.9)

Salient features—

1) Body with numerous pores called ostia.

2) Multicellular but lacks tissue level of organisation.

3) Presence of flagellated collared cells (choanocyte).

Fig. 24.9. Examples of Porifera (diagrammatic). (A) *Leucosolenia*; (B) *Sycon*; (C) *Poterion*; (D) *Spongilla*; (E) *Euplectella*.

4) The body encloses a cavity called *spongocoel* which opens to the exterior by an aperture called *osculum*.

5) Presence of canal system through which flows water current carrying food and and oxygen.

6) Asymmetrical or radially symmetrical bodies.

7) All are sessile.

8) Skeleton formed by calcareous (made up of calcium) or silicious (made up of silica) *spicules*, or spongin fibres (made up of a chemical called (*spongin*)

Phylum porifera is divided into three classes:—*Calcarea, Hexactinellida* and *Demospongiae*

1. *Class Calcarea:* e.g., *Sycon.*

Salient features—

1. Possess large collared cells.

2. Skeleton of free calcareous spicules.

2. *Class Hexactinellida:* e.g., Euplectella, *Hyalonema*

Salient features—

1) Siliceous spicules are present.

2) Choanocytes are restricted to finger-like simple or folded chambers.

3. *Class Demospongiae:* e.g. *Euspongia, Spongilla*

Salient features—

1) Skeleton is of spongin fibres.
2) Choanocytes are very small, round type of flagellated chambers.

3. **Phylum—Coelenterata** (Fig. 24.10)

Salient features-

1) Radially symmetrical, diploblastic metazoa.
2) Presence of only one permanent aperture the mouth which is surrounded by the tentacles.
3) Body is tubular having a single internal body cavity known as coelenteron.
4) Special stinging cells, nematocysts are present in the ectoderm layer. These cells are in majority in the tentacle region and are used for capturing prey.
5) Solitary or colonial.
6) Coelenterates exist in two forms—Polyp (representing asexual phase) and the Medusa (representing sexual phase).

Fig. 24.10. Examples of Coelenterate (diagrammatic): (A) *Hydra*; (B) *Aurelia*; (C) Sea-anemone; (D) *Obelia*; (E) Sea pen; (F) *Physalia*.

7) Metagenesis occur, polyp stage reproduces asexually to produce medusa. The medusa bear reproductive organs. These organs release reproductive cells which unite and finally give rise to polyp stage.

Phylum Coelenterata is divided into two subphyla-Cnidaria and Acnidaria.

I. SUB-PHYLUM CNIDARIA:

Salient features—

1) Possess nematocysts or stinging cells.

Cnidaria is divided into following classes—

Class Hydrozoa: e.g., *Hydra, Obelia*

Salient features—

1) Metagenesis is usually distinct (*except in hydra*)
2) Coelenteron is undivided.

Class Scyphozoa: e.g. *Aurelia, Pilema*

Salient features—

1) Adults exist only in medusoid stage and polypoid stage is short.
2) Gonads are horse shoe shaped.

Class Actinozoa: e.g., *Pennatula, Gorgonia.*

1) They exist only in polyp form.
2) Members are exculsively marine.

II SUB-PHYLUM ACNIDARIA: Acnidaria includes only one class Ctenophora (Fig. 24.11).

Class Ctenophora: e.g., *Pleurobranchia (Comb-jelly)*

Salient features—

1) They do not have polyp forms.
2) Coelenteron has a system of canals.
3) Locomotory organs comprise eight specialised structures called comb-plates (costae).

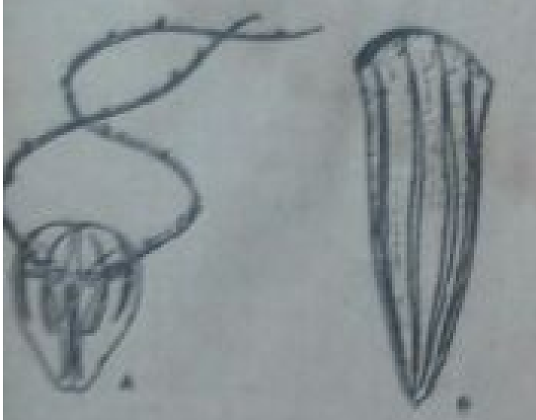


Fig. 24.11. Examples of Ctenophora (diagrammatic): (A) Comb-jelly; (B) *Beroe*.

4. **Phylum Platyhelminthes** (Fig. 24.12)

Salient features—

1) Flat, triploblastic, acoelomate and bilaterally symmetrical animals.
2) Definite anus, circulatory and respiratory organs are absent.
3) Free living or parasitic.
4) Ectoderm with cilia in free living or with cuticle in parasitic forms.
5) No skeleton.
6) Alimentary canal branched or unbranched with only a single opening (mouth) or no alimentary canal (as in Tape worm).

Phylum Platyhelminthes is divided into following classes.

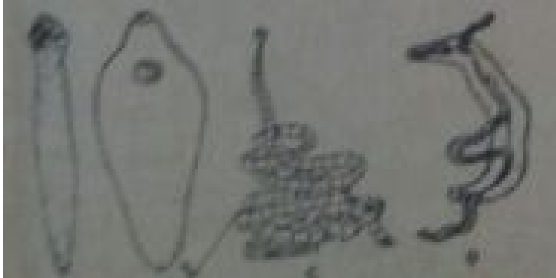


Fig. 24.12. Examples of Platyhelminthes (diagrammatic): (A) *Planaria*; (B) Liver-fluke; (C) Tape-worm; (D) *Schistosoma*

Class Turbellaria: : e.g. Planaria.

Salient features—

1) Free living with cilia on epidermis.
2) Mouth is ventral without suckers.

Class Trematoda: e.g., *Clonorchis, Fasciola*

Salient features—

1) All are parasitic
2) Body covered with cuticle.
3) Presence of one or more suckers for attachment.
4) Mouth is anterior.

Class Cestoda: e.g., *Taenia solium*

Salient features—

1) Endoparasites (live as parasite inside the body of the host.)
2) Body is divided into segments.
3) Organs of attachment are hooks or sucker.
4) Digestive tract and sense organs are absent.

5. **Phylum Nemathelminthes** (Fig 24.13)

Salient features—

1) They are unsegmented, bilaterally symmetrical, Triploblastic and pseudocoelomate.

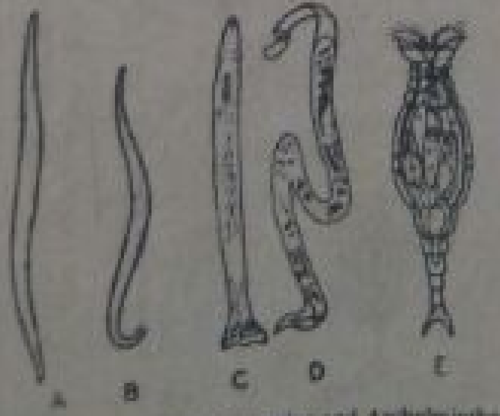


Fig 24.13 Examples of Nemertina and Aschelminthes (A) *Ascaris* (Female); (B) *Ascaris* (Male); (C) Sagitta; (D) Nemertini; (E) Rotifer

2) Body is generally covered with cuticle.
3) Blood vascular system is absent.
4) Alimentary canal is provided with distinct mouth and anus.
5) Excretory system consists of a pair of lateral canals opening externally by a single pore.
6) Sexes are separate. e.g. *Ascaris* (Round worm) *Anclyostoma* (Hook worm), *Dracunculus* (Guinea worm).

8. **Phylum Annelida** (Fig 24.14)

Salient features—

1) The body is cylindrical and elongated.
2) Body is made up of segments or metameres (both externally and internally).

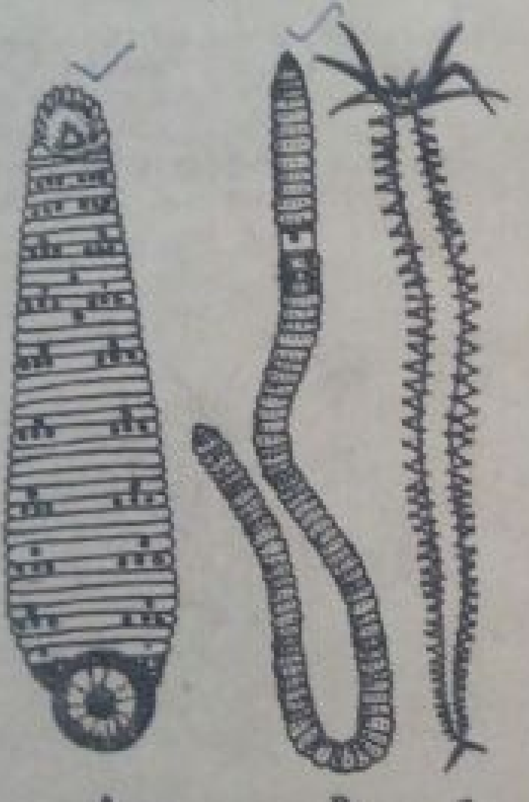


Fig. 24.14 Examples of Annelida (diagrammatic); (A) Leech (*Hirudo*); (B) Earthworm; (C) *Nereis*.

3) Triploblastic and coelomate animals.
4) Blood vascular system is usually of closed type or haemocoel may be present.
5) Excretion by metamerically arranged pairs of coiled tubes called nephridia.
6) Nervous system is well recognised and in most cases represented by cerebral ganglia and double ventral nerve cord with segmentally arranged ganglion.
7) Alimentary canal with mouth and anus at the opposite ends.
8) Reproduction asexual and sexual (both Monoecious and dioecious forms are found.).

Class Hirudinea: e.g., *Hirudinaria* (Leech), *Glossiphonia*

Salient features—

1) Body consists of definite and limited number of segments with secondary rings (annuli) externally.
2) Possess suctorial anterior sucker and a powerful posterior sucker.
3) Haemocoel present.

Class Archiannelida: e.g., *Polygordius*.

Salient features—

1) Setae are absent.
2) External segmentation is indistinct

Class Polychaeta: e.g., *Nereis*.

Salient features—

1) Normally the head is distinct with tentacles.
2) Trunk segments bear parapodia (locomotory organ) with setae.
3) Circulation closed.
4) Sexes separate.

Class Oligochaeta: e.g., *Pheretima* (Earthworm)

1) Head is in distinct.
2) No Parapodia, setae present.

3) Usually hermaphrodite
4) Clitellum is present.

7. **Phylum Arthropoda**

Salient features—

1) Body is metamerically segmented with perfect bilateral symmetry.
2) Anterior segments form a distinct head.
3) A pair of externally jointed appendages are present in each segment.
4) Body is covered with an external skeleton made of chitin.
5) Body cavity is much reduced and acts as haemocoel.
6) Circulatory system is of open type.
7) Usually possess compound eye (each eye is made up of several visual elements).
8) Respiration by trachae, gills, booklungs or body surface.
9) Excretion by Malpighian tubules.

Phylum Arthorpoda is divided into four classes — Crustacea, Myriapoda, Insecta and Arachnida.

1. *Class Crustacea*: (Fig. 24.15) e.g., Crab, Prawn, Cyclops, Daphnia.

Salient features—

1) Body is divisible into Cephalothorax and abdomen.
2) All the segments bear appendages.
3) Two pairs of antenna.

2. *Class Myriapoda:* (Fig. 24.17) e.g., Centipedes and millipedes.

Salient features—

1) Body divisible into head and trunk
2) One pair of antenna.
3) Trunk segments numerous and with one or two pairs of legs.

Fig. 24.15. Examples of Crustacea (Arthropoda); (diagrammatic); (A) Prawn; (B) Crab; (C) Cyclops; (D) Daphnia; (E) *Oniseus*.

3. *Class Insecta*: (Fig. 24.16) e.g. Hony bee, Butterfly, Bed bug, Cockroach, house fly, (leaf insect) *Culex*, *Anopheles*, wasp etc.

Fig. 24.16. Examples of Insects (Arthropoda); (diagrammatic): (A) Butterfly; (B) Honeybee; (C) Bed bug; (D) Cockroach; (E) Housefly; (F) Mosquito.

Salient features—

1) Body divisible into head, thorax and abdomen.
2) One or two pairs of wings are present on the dorsal side of the thorax.
3) Respiratory organs are in the form of trachea.
4) Three pairs of thoracic legs are present.
5) Abdomen is devoid of appendages.
6) One pair of antenna.

4. *Class Arachnida*: (Fig. 24.17) e.g., Scorpion, spider.
   1) Head is without antenna.
   2) Four pairs of legs are present.
   3) Respiratory organs are book-lungs or tracheae.

8. **Phylum—Mollusca** (Fig 24.18)

Salient features—

1) Possess soft and unsegmented body.

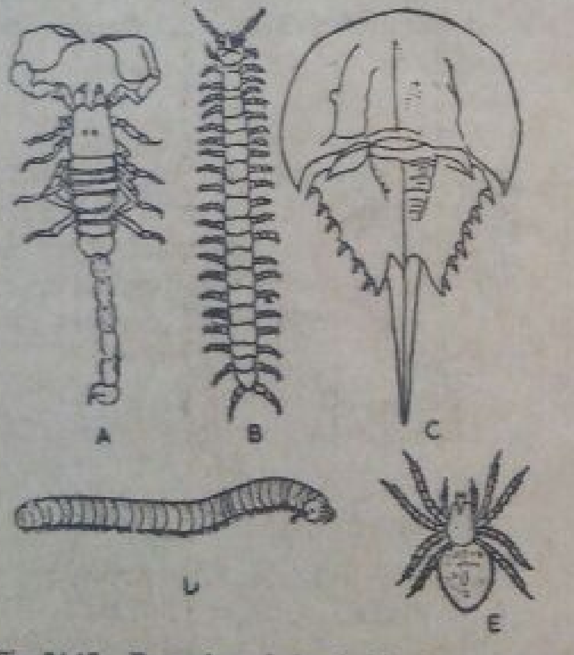


Fig. 24.17. Examples of Arachnida (Arthropoda); Diagrammatic; (A) Scorpion; (B) Scolopendra; (C) Kingcrab; (D) Millipede; (E) Spider.

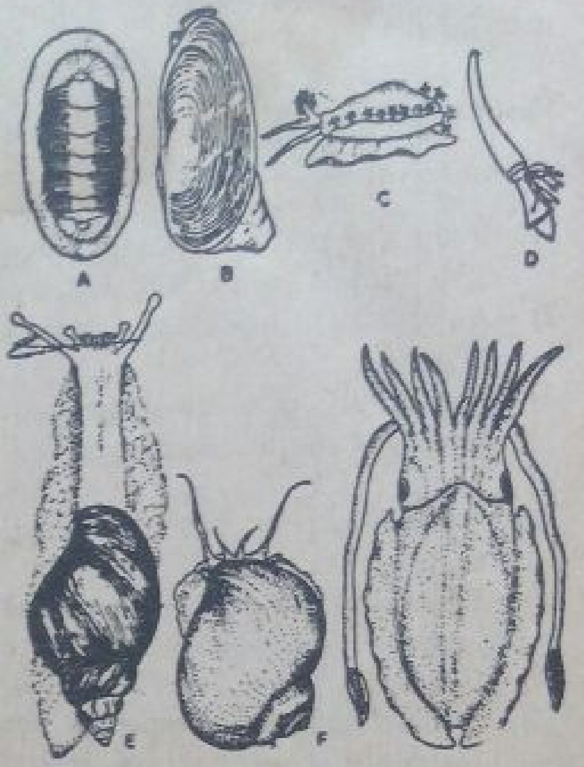


Fig. 24.18. Examples of Mollusca (diagrammatic): (A) Chiton; (B) *Unio*; (C) *Cypraea*; (D) *Dentalium*; (E) *Achatina*; (F) *Pila*; (G) Sepia.

2) Exoskeleton in the form of shell is present in majority of them.
3) Tentacles and sense organs are present in most of the members excepting Bivalves.
4) The locomotory organ is in the form of muscular foot, which may be modified in various ways.
5) Triploblastic, coelomate but with reduced coelom.
6) Visceral mass is enclosed by a thick muscular fold of the body wall called mantle.
7) Respiration by specialised structures like ctenidia (gills) and pulmonary sacs.

Phylum Mollusca is divided into following classes:

Polyplacophora: e.g., *Chiton*

...ent features—

Bilaterally symmetrical, dorsoventrally flattened body.

Dorsal side of the body is covered by a shell consisting of eight plates.

Bivalvia: e.g., *Unio, Lamellidens*

...ient features—

Body is enclosed by bivalved shell.

Foot is tongue shaped.

Gastropoda: e.g., *Pila, Achatina*

...ient features—

Mostly they have spirally twisted shell.

Foot is differentiated into three parts

Cephalopoda: e.g., *Sepia, Octopus Loligo, Nautilus*

...ient features—

Internal shell (excepting *Nautilus*)

Foot is modified into oral arms and siphon for swimming.

Well developed head with eyes and arms.

...addition to above four classes, ...her three classes are as follows:

Monoplacophora e. g., Neopilina.

Solenogastres e.g., *Chaetoderma*

Scaphopoda e.g., *Dentalium*

...ylum Echinodermata (Fig. 24.19)

...ient features—

Pentaradial symmetry in adult, but bilateral symmetry in larvae.

Distinct head is lacking.

The surface of the body is covered by calcareous spines and ossicles (tough covering).

Water vascular system is present, locomotory organs are tubular, ...podia.

Fig. 24.19. Examples of Echinodermata (diagrammatic): (A) Starfish; (B) Sea cucumber; (C) *Antedon*; (D) *Hellaster*; (F) *Clypster*; (F) Sea urchin.

Phylum Echinodermata is divided into two subphyla. Eleutherozoa and Pelmatozoa.

I. Sub Phylum Eleutherozoa is divided into following classes:

Class Asteroridea e.g., *Asterias* (Star Fish).

Salient features—

1) The body is star-shaped or pentagonal with a flattened central disc.
2) The arms are usually five not sharply separated from the central disc, hollow and contains tube feet.

Class Echinoidea: e.g., *Echinus* (Sea urchin).

Salient features—

1) The body may be globular, heart-shaped, oval or disc-like.
2) The body is enclosed by a skeleton in the form of a continuous test of closely set Calcareous plates with movable spines.

Class Holothuroidea: e.g., Holothuria (Sea cucumber)

Salient features—

1) The body is cylindrical, sac like
2) The skin is soft, thin and without spines.

Class Ophiuroidea: e.g., *Ophiura*

Salient features—

1) The body is pentamerous, flattened with distinct oral and aboral surfaces.
2) There are no spacious prolongations of the coelom into the arms.
3) There are five arms which are sharply separated from the central disc.

In addition to above four classes, there is one more class, called Ophiocistiodea e.g., *Sollasina*

II. SUB-PHYLUM PELMATOZOA

Salient features—

1) Contains a large number of fossil echinoderms.
2) The members usually remain fixed throughout life or only in the young stage by aboral side or by a stalk. Sub-phylum Pelmatozoa is divided into five classes, out of which only the class Crinoidea includes living form.

Class Crinoidea: e.g., *Antedon*, (Sea-lily).

Salient features—

1) The arms are movable branched.
2) Pentamerous symmetry.

Outline classification of the phylum chordata

There are some differences of opinion among zoologists with regards to details of classification of the phylum chordata. The phylum is divided into three sub-phyla, urochordata, cephalochordata and vertebrata. The uro and cephalo-chrodates are primitive chordates and are collectively known as protochordates. They do not have a cranium or brain box and are also therefore called Acraniata in contrast to all other chordates which are referred to as craniata. Another group of animals called hemichordates has also been generally considered by many zoologists to be protochordates and included in phylum chordata as a separate sub-phylum. The hemichordata includes marine, worm-like animals such as Balanoglossus found on the Indian coasts. They have an elongated body divisible into proboscis, collar and trunk possessing true pharyngeal gill slits like chordates (Fig.24.20).

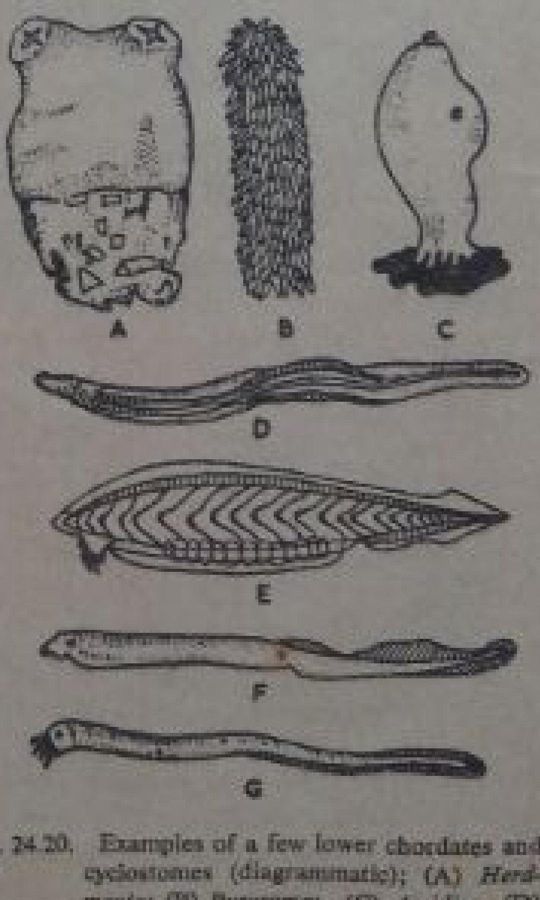
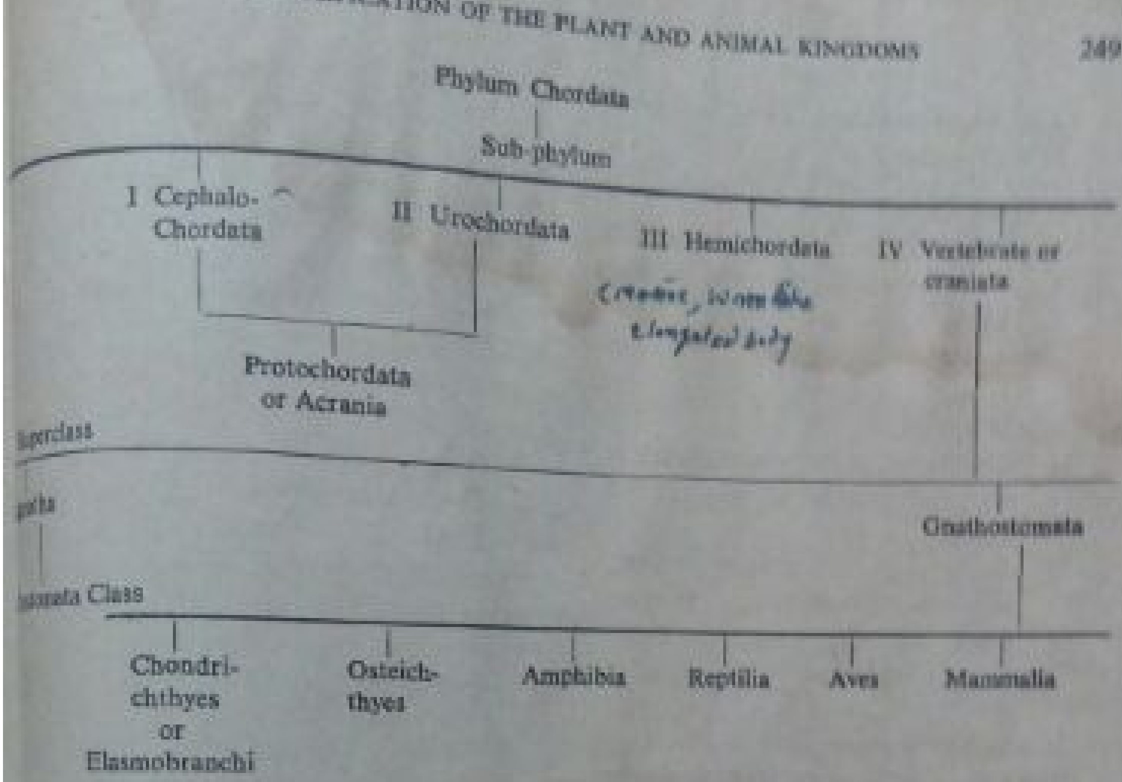


Fig. 24.20. Examples of a few lower chordates and cyclostomes (diagrammatic); (A) *Herdmania*; (B) *Pyrosoma*; (C) *Ascidia*; (D) *Balanoglossus*; (E) *Amphioxus*; (F) Lamprey; (G) Myxine.



SUB-PHYLUM I CEPHALOCHORDATA

1. Body laterally compressed; elongated and pointed at both ends.
2. No paired fins but median fins present.
3. Pharynx greatly enlarged and provided with numerous gill slits.
4. Pharynx surrounded by a large chamber called atrium which opens to the outside by an aperture (atriopore).
5. Notochord persists throughout life.
6. Myotomes externally visible.
7. Nerve cord tubular and dorsal to notochord; no definite brain.
8. Anus posterior to the atriopore.
9. Post anal tail present.
10. Marine; 28 species are known.

Example: *Branchiostoma* (Amphioxus)

SUB-PHYLUM II UROCHORDATA

1. Body covered by a tunic or test containing cellulose.
2. Notochord present only in larval stage and confined to the tail region.
3. Nerve cord tubular and dorsal in the larval stage and greatly reduced in the adult.
4. Pharynx greatly enlarged with many gill slits.
5. Pharynx surrounded by atrium which opens outside by atriopore.
6. Anus opens into the atrium.
7. Larvae free swimming; adults sessile or free swimming.
8. All marine.

Examples: *Ascidia*, *Herdmania*, *Salpa*, *Doliolum*

SUB-PHYLUM III HEMICHORDATA (For features, see p. 248)

Example: Balanoglossus

SUB-PHYLUM IV VERTEBRATA

1. Body with bony or cartilaginous endoskeleton.
2. Presence of vertebral column.
3. Caranium or brain box distinct.
4. Head well developed and provided with sense organs.

5. Paired lateral appendages usually present.
6. Post anal tail usually present.

Super-class Agnatha
1. No jaws.
2. No lateral appendages.

Class Cyclostomata (Greek, *cyklos*, circular + *stoma*, mouth)
1. Body, rounded, slender and eel-like.
2. Skin, with mucous gland, no scales.
3. No paired fins but median fins present.
4. Ventral suctorial mouth, single nasal sac.
5. Six to fourteen pairs of gills.
6. Notochord persistent, skeleton fibrous and cartilagenous.
7. Fresh water or marine.

50 species are recorded.
Examples: *Petromyzon* (lamprey), *Myxine* (hagfish).

Super-class Gnathostomata.
1. Jaws present.
2. Usually paired appendage present.

Class Chondrichthyes (Greek, *chondra*, cartilage + *ichthys*, fish) (Fig. 24.21)
1. Body fusiform, caudal fin heterocercal.
2. Mouth ventral; two nasal sacs present.
3. Skin with placoid scales.

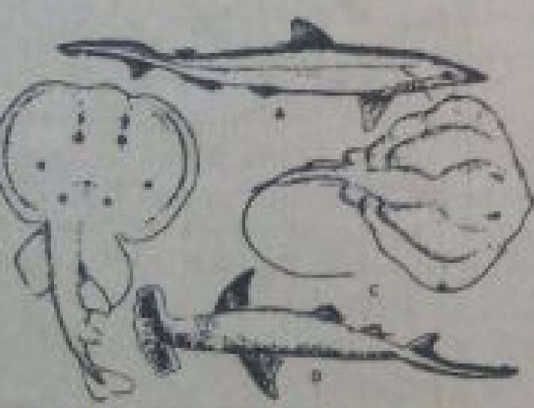


Fig. 24.21. Example of a few cartilagenous fishes (diagrammatic): (A) *Scoliodon*; (B) Electric ray; (C) Stinging ray; (D) Hammer-headed shark

4. Skeleton cartilaginous, fin with cartilaginous rays.
5. Both paired and unpaired fins are present.
6. Pelvic fins in males are provided with claspers.
7. Five to seven pairs of gills, no operculum.
8. Lateral line system with cutaneous receptors present.
9. Ten pairs of cranial nerves.

About 550 species are known; all marine.
Examples: *Scoliodon* (dog fish), *Torpedo* (electric ray), *Rhinobatus* (guitarfish), *Raja* (common ray), *Zygaena* (hammer headed shark).

Class Osteichthyes (Greek *OS*, bone + *ichthys*, fish) (Fig. 24.22).
1. Body fusiform, tail usually homocercal.
2. Mouth terminal, two nasal sacs present.
3. Skin with cycloid or ctenoid scales, some without scales.
4. Skeleton more or less bony, fins with bony rays..
5. Both paired and unpaired fins present.
6. Four pairs of gills covered by bony operculum.
7. Lateral line system present.
8. An air-filled bag—Swim bladder is usually present.
9. Ten pairs of cranial nerves.

About 30,000 species are known; marine or fresh water.
Examples: *Anabas* (koi) *Clarias* (magur), *Catla*, (katla), *Labeo* (Rohu) *Cirrhinus* (mrigal), *Protopterus*(lung fish)

Class Amphibia (Greek, *amphi*, double or both, + *bios*, life) (Fig.24.23)
1. Skin, smooth and moist with mucous glands, chromatophores present.
2. Two pairs of limbs, digits without claws.
3. Body with distinct head and trunk, no neck.
4. Two nostrils opening into the buccal cavity.

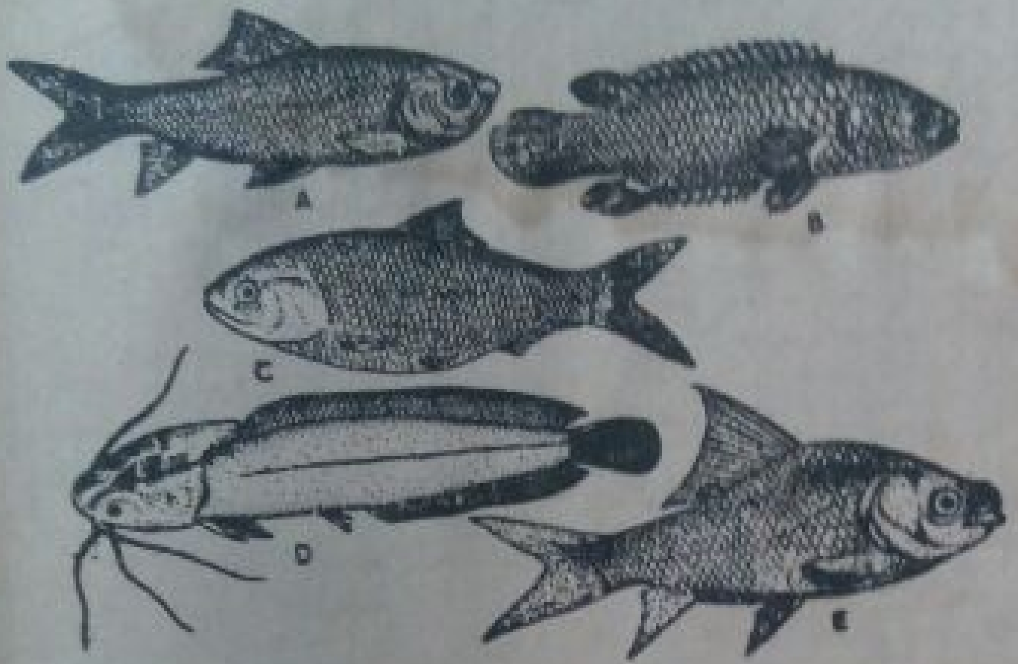


Fig. 24.22. Examples of a few bony fishes (diagrammatic); (A) Rohu; (B) Koi; (C) Hilsa; (D) Magur; (E) Catla.

Fig. 24.23. Examples of a few amphibians (Diagrammatic); (A) Salamander; (B) Toad; (C) Frog; (D) *Necturus*; (E) *Ichthyophis*.

5. Tympanum present.
6. Lateral line system usually absent in the adults but in some aquatic forms it may be present.
7. Larval stage tailed and mostly aquatic.
8. Ten pairs of cranial nerves.
9. Three chambered heart.

About 2500 species are known; none is marine; Amphibians live in fresh water or in both habitats. .

Example: *Bufo* (toad), *Rana* (frog), *Tylototriton* (Himalayan salamander found in Darjeeling area of West Bengal). *Ichthyophis* (Limbless amphibian).

Class Reptilia (Latin, *repere*, to crawl) (Fig. 24.24)

1. Body covered with horny epidermal scales.
2. Body usually divisible into head, neck, trunk and tail.

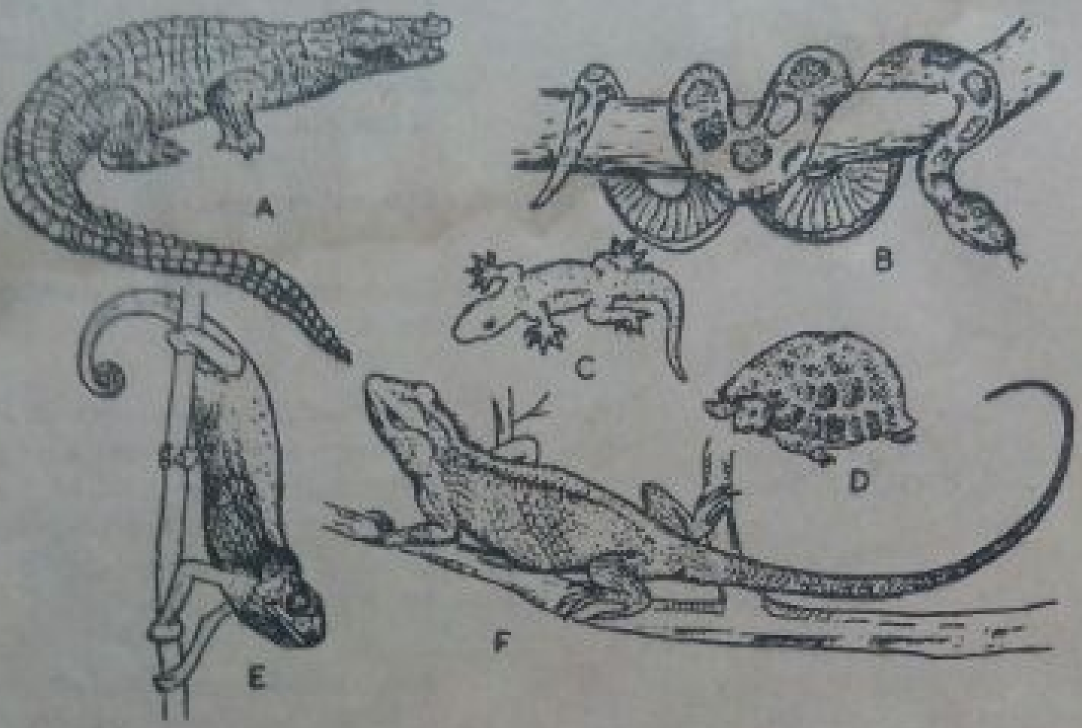


Fig. 24.24. Examples of a few reptiles (diagrammatic);
(A) Crocodile; (B) Snake; (C) Lizard; (D) Turtle; (E) *Chamaeleon*; (F) *Calotes*.

3. Paired pentadactyl limbs (absent in snakes) with clawed digits.
4. No lateral line system.
5. Tympanum small and depressed.
6. Copulatory organs (hemipenis) present in males.
7. Egg covered with hard calcareous shell.
8. Twelve pairs of cranial nerves.
9. Mostly terrestrial, some aquatic (marine or fresh water).
10. Heart, generally three-chambered except crocodile (four-chambered).
11. Right and left aortic arches present.

About 6,300 species are known.

Examples: *Calotes* (garden lizard), *Hemidactylus* (house lizard), *Crocodilus* (crocodile) *Gavialis* (gharial), *Naja* (cobra), *Lissemys* (turtle), *Python*, *Ptyas* (rat snake), *Chamaeleon*.

Class Aves (Latin, *Avis*, bird) (Fig. 24.25)

1. Body boat shaped, covered with feathers, scales are present on the hind limbs.
2. Head, neck, trunk, and tail present.
3. Jaws with horny beak, no teeth.
4. Forelimbs modified into wings for flying.
5. Hind limb with four digits adopted for perching, walking or swimming.
6. Skeleton light and provided with air cavities.
7. Warm blooded, heart four-chambered, only right aortic arch present.
8. Syrinx (voice box) present.
9. Lungs with air sacs.
10. Only left ovary and oviduct present in the females.
11. All oviparous, egg with much yolk and calcareous shell.

Fig. 24.25. Examples of a few birds (diagrammatic): (A) Kite; (B) Cuckoo; (C) Cock; (D) Sparrow; (E) Pigeon.

12. Generally terrestrial but some are adapted to aquatic life.

About 8,600 species are known.

Example: *Columba* (Pigeon), *Milvus* (kite), *Cuculus* (cuckoo), *Struthio* (ostrich, a flightless bird), *Gallus* (fowl).

Class Mammalia (Latin, *mamma*, breast) (Fig 24.26)

1. Body covered with hair.
2. Body divisible into head, neck, trunk and tail; tail absent in some.
3. Presence of mammary glands.
4. Sweat and sebaceous glands present in the skin.
5. External ear present.
6. Digits usually ending in claws, nails or hoofs.
7. Dentition thecodont (teeth in sockets of jaw bones) and generally heterodont (four types: incisor, canine premolar, molar); homodont (similar kind of teeth) only in toothed whale.
8. Warm blooded, heart four chambered, only left aortic arch present.
9. Muscular partition called diaphragm separating the thoracic cavity from the abdominal cavity.
10. Higher mammals are viviparous (some primitive mammals are oviparous).
11. Foetus (embryo) is nourished by the mother through a structure called placenta.

About 3,700 species of mammals are known.

Example: *Panthera leo* (lion), *Panthera tigris* (tiger), *Pteropus* (bat), *Hylobates* (gibbon), *Elephas indicus* (elephant) *Macaca* (monkey), *Canis familiaris* (dog), *Bandicoota bengalensis* (Bandicoot), *Camelus* (camel), *Bos indicus* (cow), *Platanista gangetica* (dolphin), *Funambulus* (squirrel), *Presbytis* (Langur), *Oryctolagus* (rabbit), *Cavia* (guineapig).

Fig. 24.26. Examples of a few mammals (diagrammatic):
(A) Tiger; (B) Lion; (C) One horned rhinoceros; (D) Monkey; (E) Camel; (F) Rat

EXERCISES

1. State briefly the criteria used for the description of plants.
2. What is meant by a floral formula? Give the floral formula of a regular, bisexual, epigynous flower with free sepals, 5 united petals, 5 free stamens and 2 united with inferior ovary.
3. What is a floral diagram? What are its advantages?
4. Give a floral diagram indicating the following :
   (*a*) Cohesion of 5 sepals.
   (*b*) Adhesion of 5 petals and 5 stamens.
   (*c*) Two united carpels showing axile placentation
   (Only the parts mentioned need be shown).
5. Name at least three plants of economic importance belonging to *Leguminosae*. Name the plant parts which are used. Scientific names should be given.

6. What are the scientific names of the following plants :
(*a*) Onion, (*b*) Radish, (*c*) Night jasmine, (*d*) Pea , (*e*) Groundnut ?
7. Name the families to which the following plants belong. Mention the diagnostic characters of the families;
(*a*) *Allium sativum* L.; (*b*) *Lycopersicon esculentum* Mill; (*c*) *Cajanus cajan* Mill; (*d*) *Helianthus annuus*.
8. Distinguish between the following families :
(*a*) *Cruciferae* and *Solanaceae*,
(*b*) *Compositae* and *Liliaceae*.
9. What is the kind of fruit found in *Cruciferae*, *Solanaceae*, *Compositae* and *Liliaceae* ? Give examples of 2 plants in each case with their scientific names.
10. Give the floral formulae of *Solanaceae*, *Liliaceae*, *Cruciferae* and *Compositae*.
11. Describe the following:
(*a*) Flower of *Papilionoideae*,
(*b*) Capitulum of *Compositae*.
12. How can you distinguish between *Papilionoideae*, *Caesalpinioideae* and *Mimosoideae* ?
13. Name the major invertebrate phyla and state the salient features of each phylum with examples.
14. Describe the diagnostic features of the phylum chordata.
15. What are protochordates? Name the sub-phyla of the protochordates.
16. Name the classes under the sub-phylum vertebrata. State the salient features of each phylum with examples.
17. Write short notes on :
(*a*) Acrania, (*b*) Craniata, (*c*) Cyclostomata.

CHAPTER 25

Collection and Identification of Animals and Plants

Field Observations and Records

EVERY biologist should have first hand information pertaining to living populations growing in different habitats under various climatic conditions. This line of study may be pursued through field observations and records. A field notebook is essential for studying plants and animals in the field because it is useful not merely for recording the names of the plants and animals observed, but it also gives us an idea about the flora and fauna of a particular locality, the habitats under which the plants and animals are growing, elevation (height of the locality), location (i.e., name of the area), soil type (i.e., sandy, loamy, clayey etc.), the time of flowering of plants and the different types of plant and animal associations. For this purpose, a small, pocket-sized, bound notebook is preferable. A lead pencil or pen should also be carried with the field notebook. On the top of the page the name of the locality where the field study is conducted should be written in block letters; the date is to be written on the same line on the right hand side; a brief introduction referring to the habitat, locality, date of collection, weather conditions, altitude, number of members in the party led by the teachers should be given. After this, it is advisable to make two columns, the first one containing the full scientific name of the plant or animal including the name of the family with a serial number (so that it can be referred to later on with the actual specimen collected for preparing a herbarium sheet or for other types of preservation); the local name, if possible, may be given; the second column should contain information about the plant or the animal (i.e., in the case of plant, the size, whether it is flowering or not, any special feature of interest, habit, habitat etc.

and for animals their characteristic features). It is also advisable to keep two notebooks, one for rough use in the field and a fair notebook which is to be kept at home. All the information recorded in the first notebook should be copied neatly into the second one which should be signed by the teacher-in-charge.

Collection and Methods of Preservation of Some Animals and Plants

A collection of specimens from the natural habitat is the first thing to be done in systematics. A knowledge of systematics of any group of organisms will remain incomplete unless one goes to the field and makes observations of the habit and habitat of the animals and plants concerned.

COLLECTION AND METHODS OF PRESERVATION OF ANIMALS

The methods of collection and preservation of animals vary from group to group. But in all cases collected specimens should be properly killed, suitably fixed, correctly identified, labelled and carefully preserved. All the identified material should be subsequently catalogued and stored in a museum for future reference.

Methods of collection and preservation of some common animals are described below.

Pila and Achatina (Gastropoda, Mollusca)

Pila is a fresh water mollusc but it can also live on land. Therefore, it is known as an amphibious snail. It is a soft bodied sluggish animal having an external shell. It can be easily collected by hand or dredged from the shallow waters of lakes, ponds, ditches and paddy fields when under water. While collecting *Pila*, the habitat of the animal should be recorded.

For the study of its external features, place a *Pila* in a tray filled with water and note the head with tentacles, eyes and the foot as the animal starts creeping. Living *Pila* can be easily reared in the aquarium.

Fully relaxed good specimens are needed for detailed study. *Pila* can be narcotized by menthol or magnesium sulphate or chloral hydrate. Any one of these narcotizing agents may be added gradually in small quantities to the water in the tray containing the animal. Within 24 hrs., the mollusc will be completely narcotized and fully extended.

Achatina, the land snail, is found in crop fields, grassland and forests. It may be killed by plunging it into a water-filled jar and tightly closing the lid. The animal dies in a relaxed condition and does not need any narcotization.

Marine molluscs can be collected from coral reefs or rocks in shallow water when these are exposed at low tide. These can also be narcotized like the *Pila*.

The most suitable preservative for all molluscs including *Pila* and *Achatina* etc., is 95% ethyl alcohol or rectified spirit. Formalin destroys the molluscan shell gradually and is therefore, not a suitable preservative.

Examine a preserved or fresh mollusc and note carefully the following features.

1. Shell
2. Mouth aperture
3. Eyes
4. Tentacles, etc.

Cockroaches (Insecta, Arthropoda)

These insects are very commonly found in houses particularly in kitchens, stores, lavatories etc. They are omnivorous animals feeding on whatever is available and are usually nocturnal in habit. They can be collected easily by hand or in a small net. They can be killed by placing them in a bottle containing some cotton wool soaked in chloroform. The best way to preserve a cockroach is to pin it on a corkboard. The

pin should be inserted through the pro-thorax, the wings spread out and the animal left to dry for some days. The cockroaches, as other insects can also be preserved in rectified spirit. Examine a preserved specimen and note the following features:

1. Body divisible into head, thorax and abdomen.
2. The eyes, antennae and the mouth parts located in the head region.
3. Two pairs of wings on the thorax.
4. Three pairs of jointed legs on the ventral side of the thorax.
5. Segmented, dorso-ventrally flattened abdomen.
6. A pair of anal cerci at the posterior end of the abdomen.
7. In addition to the anal cerci the males have a pair of anal styles at the posterior end of the abdomen.

Prawn (*Crustacea, Arthropoda*)

Prawns, found all over India, inhabit fresh water streams, rivers, lakes, and ponds. They prefer slow-moving and clean water and usually stay near the bottom. At night they come to the surface in search of food which consists of algae, moss, other weeds and insects. Prawns can be collected by nets or by dredging. On being kept out of water for some time, they die and can be preserved in about 5% formalin or rectified spirit.

Examine the preserved specimens and note the following features:

1. Body divisible into a cephalothorax and abdomen.
2. A hard shield-like carapace covering the cephalothoracic region which contains a rostrum, a pair of stalked eyes, a pair of antennae and five pairs of legs.
3. Six-segmented abdomen with five pairs of swimming appendages, one pair of uropods and a spine-like telson at the posterior end.

A Teleost Fish (*Osteichthyes, Chordata*)

Fishes may be collected from rivers, ponds, lakes and the sea. Different kinds of nets are used to catch fishes. Fishes die if kept out of water for sometime. However, some fishes like *Anabas* (Koi), *Heteropneustes* (Singi), *Clarias* (Magur), *Chana* (snake-headed fishes) etc., do not die out of water because they can breathe air. They can be easily killed by keeping them submerged under water. All fishes can readily be killed by placing them in 2-3% formalin. A small incision should be made in the belly of the fish specimens which are thick or longer than 75 mm so as to allow the formalin to enter the body cavity, or formalin may be injected into the body to preserve the visceral organs. Although 5-10% formalin is used as a preservative, 90% alcohol is preferable. Formalin irritates the eyes and it is rather difficult to work with formalin-preserved specimens.

Examine a preserved fish and note the following features:

1. Nature of mouth aperture.
2. Barbels (thread like projections on the jaws).
3. Eyes and nasal openings.
4. Operculum.
5. Lateral line.
6. Fins (both paired and unpaired)
7. The type of scales—cycloid, ctenoid; count the scales in the lateral line.

Frogs and Toads (*Amphibia, Chordata*)

Frogs and toads are very common throughout India. Frogs are found in or near ponds. Toads are terrestrial and mostly nocturnal. Frogs can be collected in nets and can also be baited. Toads are easily captured by hand. Frogs and toads die when kept in a

closed jar containing cotton soaked in chloroform.

Small-sized frogs and toads are fixed in 4% formalin. For larger specimens 6% formalin should be injected in the digestive tract. The animals then may be preserved in 4-5% formalin. Alternatively, formalin fixed specimens should be washed with water and then transferred to 90% alcohol for better preservation.

Examine a preserved toad or frog and note the following features:

1. Mouth aperture.
2. Tongue.
3. Teeth (if any).
4. Eyes and eyelids.
5. Parotid gland (if present).
6. Skin and its colour.
7. Nature of the fore limbs, hind limbs and digits.
8. Vocal sac and thumb pads (in males)

Lizard (*Reptilia*, *Chordata*)

Garden lizard (*Calotes*), wall lizard (*Hemidactylus*), can be trapped as well as netted. Chloroform vapour may be used to kill them as in the case of toads and frogs. Either rectified spirit or 3-4% formalin solution is a suitable preservative.

Examine a preserved specimen and note the following:

1. Mouth aperture.
2. Tongue and teeth.
3. Eyes and eyelids.
4. Scaly skin.
5. Nature of the limbs and clawed digits.
6. Nature of cloacal aperture.
7. Tail.

Pigeon (*Aves*, *Chordata*)

Pigeons can be collected by using traps as well as nets. A shotgun may also be used. Birds can be killed by chloroform vapour.

Put a pigeon inside a glass jar and place some cotton soaked in chloroform. The pigeon will die within a few minutes. A pigeon may be preserved wet. Suitable preservatives are 75-80% alcohol or 4% formalin with some common salt added to it. Make a small incision in the abdomen of the pigeon or inject sufficient quantity of one of the preservatives into the abdominal cavity and then submerge the pigeon in alcohol or formalin in a jar.

Examine a freshly killed or preserved pigeon and note the following:

1. Body divisible into head, neck and trunk.
2. Mouth and beak.
3. Tympanum.
4. Nasal apertures.
5. Eyes and eyelids.
6. Wing and tail feathers.
7. Hind leg.
8. Anal aperture.

Rat (*Mammalia*, *Chordata*).

Rats can be easily collected by traps. Rat poison may also be used. Follow the method of killing and preservation as in the case of the pigeon.

Examine a rat and note the following:

1. Body divisible into head, neck, trunk and tail.
2. Mouth aperture and teeth.
3. Nasal aperture and vibrissae.
4. External ear.
5. Fore and hind limbs.
6. Mammary glands.
7. Genitalia.
8. Anal aperture.

COLLECTION AND METHODS OF PRESERVATION OF PLANTS

Those who are actively engaged in taxonomic work can study plant life in two ways: (1) by going out into the field to gain first-hand information through observation of living populations in diverse situations and localities, (2) by studying preserved specimens in the herbarium. The objective of field collection and preservation in a herbarium is to maintain a permanent record of a series of specimens and notes which will furnish maximum information about the plants under study.

The essential equipments (Fig. 25.1) mainly used for field work are:

1. *Plant press*: This is a device for pressing specimens flat and for drying them quickly. It consists of two wooden frames usually 45 cm long and 30 cm broad. Between the top and bottom frames are driers, usually moisture-absorbing blotting sheets (45 × 30 cm) and between these are newspaper sheets in each of which a single plant specimen is placed. The plant press is tightly bound together by a pair of straps or ropes. Care should be taken to change the driers at regular intervals; otherwise preservation will be imperfect. If the press is not available, the plant specimens may be kept between newspaper sheets and a heavy trunk or box placed on them.

2. *Vasculum*: This is a container of suitable size (50 × 30 × 15cm) made of tin or aluminium in which the specimens collected can be kept fresh before they are pressed. It has a hinged door which can be opened only towards the outside. There are two rings on either side acting as handles. Where the vasculum is not available polythene or plastic bags can be used for collecting fresh specimens.

3. *Diggers*: These are used by gardeners. When collecting plants with rhizomes, bulbs and underground parts firmly attached to the soil, a digger is necessary to scoop out such parts from the soil.

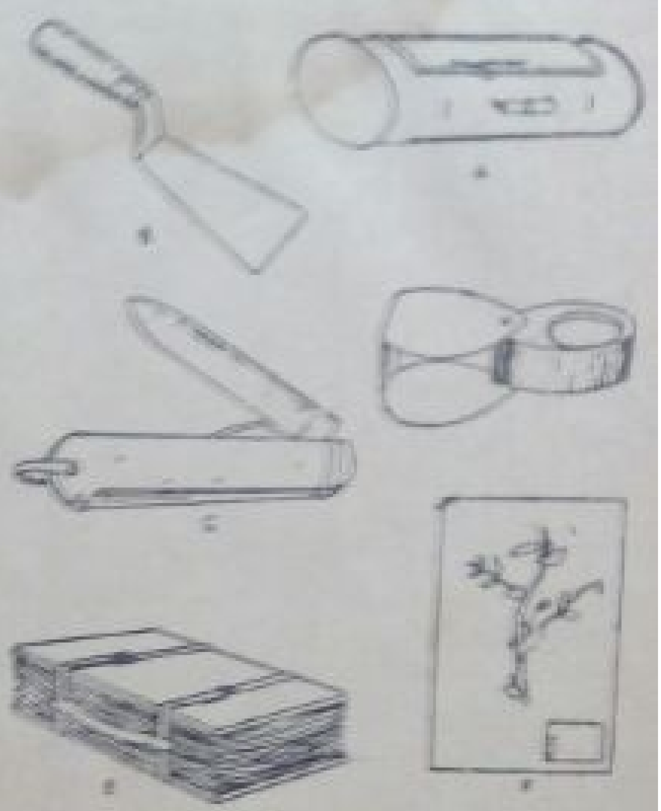


Fig. 25.1. Essential equipments for field work: (A) Vasculum; (B) Digger; (C) Knife; (D) Pocket lens; (E) Plant press; (F) Herbarium sheet.

4. *Scissors*: A large pair of scissors or pruning shears are used to cut hard branches of desired length.

5. *Knife*: preferably a pocket knife is necessary for cutting woody plants neatly or for further trimming of parts cut by scissors or pruning shears.

6. *A Pole*: A pole either of bamboo or any hard wood of fairly reasonable length and, if possible, with a hook attached at one end. In the case of large trees whose flowering branches are out of reach, a long pole proves useful.

7. *Magnifying glass*: A glass or pocket lens of about 10 magnification is very useful in the study of minute parts of the plant in the field.

. *Photographic equipment*: A camera, if ilable, may be taken to the field for otographing plants in their natural abode. otographs will give an impression about vegetation of the particular region.

9. *Labels and strings* to be attached to the ecimens collected giving the locality, date collection and the name of the plant.

10. *A field notebook* for maintaining field cords.

OW TO PRESERVE PLANTS AFTER COLLECTION

The following methods are usually employed:

1. The plants reasonably pressed and dried are mounted on herbarium sheets.

2. If fresh specimens are kept in a vasculum they should be taken out as early as possible and pressed and dried in a press.

3. When plants are collected for herbarium sheets, it is necessary to preserve those plant parts which have flowers or fruits and leaves. The specimens to be preserved should be of reasonable size so that they can be neatly mounted on herbarium sheets.

4. Specimens that have been properly dried and preserved should be carefully mounted on a herbarium sheet. A herbarium sheet is usually 42 × 28 cm in size and is made of rag paper of varying thickness. For mounting, the specimen is placed on a sheet of paper with its lower side uppermost. Paste, glue or adhesive of any kind is then applied to the exposed surface of the specimen. It is then carefully lifted from the sheet of paper and pasted on to the herbarium sheet. Thick parts which cannot be so mounted can be stitched on to the sheet by means of a strong piece of thread. Once the specimen is mounted, the herbarium sheet is left to dry. When the specimen is firmly attached to the sheet, it is put inside a paper cover. Fruits and seeds can be put into small packets and attached to the herbarium sheets.

5. Labelling should be carried out simultaneously with mounting to avoid confusion. A label of suitable size is usually used. It should bear the full botanical name of the plant, the family name, the locality and date of collection together with its habit and habitat and any other valuable information pertaining to it. The name of the collector and the name of the person who has identified the specimen are also given in the label. The accession number (serial number of the herbarium specimen) is written at the end. A herbarium label is usually stuck on the right-hand corner at the bottom of the sheet.

HERBARIUM

A herbarium sheet of a plant specimen provides a means of permanently preserving it for future reference and study. It is also used for comparison with a specimen newly collected in order to identify it or to confirm its identity. The place where herbarium sheets are arranged according to an accepted system of classification and stored for future study, is called a herbarium. There are many standard herbaria in the world of which the one at Kew in England is the best known. In India, the National Herbarium is located in the Indian Botanic Garden, Howrah (West Bengal).

Herbarium specimens should be protected from serious damage usually caused by various organisms including fungi, bacteria and insects during storage. Fungal, bacterial and insect pests may be prevented by spraying with standard fungicides, bactericides and insecticides respectively. A 0.1% solution of mercuric chloride is very useful as a preservative. Standard pesticides include DDT (Dichloro diphenyl trichloroethane), PDB (Paradichlorobenzene), carbon disulphide gas, gammaxane, neocid, etc. The entire herbarium may be fumigated (subjected to fumes) with any common fumigant at regular intervals of 1-2 years in order to kill

all infective agents. Specimens which cannot be dried properly can be preserved in a 5% formalin solution.

Identification of Plants in the Field

Identification of plants is usually accomplished by several methods. (1) Flora or manual of the desired locality, if available, may be consulted after studying the detailed characteristics of a plant, its flowers and fruits. The manual generally contains both analytical keys and descriptions of plants. When the literature of a particular region is unknown reference should be made to Blake and Atwood's *Guide to the Floras of the World*. (2) A herbarium containing the identified specimens of the desired locality may be helpful in identifying the specimens by comparison.

To identify the plants of Ranunculaceae, Nymphaeaceae, Cruciferae, Leguminosae, Solanaceae, Compositae, Liliaceae and Gramineae in the field, the following diagnostic characters of the said families must be known to the collectors:

Name of family with examples	Diagnostic characters of the family.
1. Nymphaeaceae	Aquatic herbs with rhizomatous stems,
Nymphaea rubra, *Victoria regia*	leaves long, petioled, peltate or pseudopeltate; petals 3-numerous, often passing into stamens.
2. Cruciferae *Brassica nigra*, *Raphanus sativus*	Annual, biennial or perennial herbs often with pungent watery latex; leaves radical or cauline; cruciform corolla; stamens tetradynamous; fruit siliqua.
3. Leguminosae *Pisum sativum*, *Arachis hypogea*	Roots with nodules; leaves usually compound, stipulate; flowers lateral, hypo or perigynous; fruit usually legume, sometimes lomentum.
4. Solanaceae *Solanum tuberosum* *Lycopersicon esculentum*	Leaves simple, alternate, exstipulate; calyx persistent; corolla rotate or funnel shaped; fruit many-seeded berry, sometimes capsule.
5. *Compositae* *Helianthus annuus* *Tagetes patula*	Inflorescence-a capitulum, presence of involucre of bracts; sepals modified into a hairy pappus sometimes scaly or absent; Stamens syngenesious; fruit-a cypsela.
6. *Liliaceae* *Allium cepa* *Asparagus racemosus*	Stems usually bulbous or rhizomatous; leaves cauline or radial; Floral Parts in threes; ovary superior; fruit a berry or capsule.
7. *Gramineae* *Triticum aestivum* *Oryza sativa*	Stems usually cylindrical with hollow internodes and solid nodes (a culm); leaves parallel veined with distinct sheath; ligulate; inflorescence-a spikelet, anthers versatile; stigma feathery; fruit-a caryopsis.

Any suitable local material can be provided for practical work depending upon availability.

How to Use a Key (Plants)

A key is an artificial analytical device most useful in identifying the object. Two types of keys are generally used, viz., yoked or indented key and bracketed key. In the case of the former, the user is given a sequence of choices between two or more statements of characters of the object and the user can identify the unknown object only by taking the correct choice. The indented key leads more directly to the various sub-divisions and is more easily followed. When the successive divisions of a key are arranged in pairs, the arrangement is said to be dichotomous. The dichotomous type of construction is often found in both indented and bracketed keys. In any key, each statement of a couplet is termed a lead. A bracketed key is based on the same principle of contrasting choices,

...t these are placed in the same line of the ...y and not separated by intervening lines. ...o examples of two types of keys and their ...s are given below.

...dented Key

...arpels 1-ovuled; fruit achenes
  Leaves opposite, compound
    Sepals 4, petaloid, petals-0, no tendril *Clematis*
    Sepals as many as petals, 4 or 5, third or terminal leaflet modified into tendril *Naravelia*
  Leaves alternate or radical *Anemone*
...arpels many-ovuled; fruit follicles
  Carpels united at the base; flowers regular *Nigella*
  Carpels free; flowers irregular *Aconitum*

To identify a particular genus of the above mentioned genera of the family Ranunculaceae, the user should first consider the characters of carpels and fruits of his specimen. The first choice will be between 'carpels 1-ovuled; fruit achenes' and 'carpels many-ovuled; fruit follicles' because these paired statements show same indentation. If the second group of characters, i.e., 'carpels many-ovuled; fruit follicles' are taken, the next choice, as shown by indentation is between 'carpels united at the base; flowers regular' and 'carpels free; flowers irregular'. If the specimen shows the fruit a follicle, irregular flower and free carpels, it is definitely a member of the genus *Aconitum.*

Bracketed Key

(1) Carpels 1-ovuled; fruit achenes......(2)
(1) Carpels many-ovuled; fruit follicles..(4)
(2) Leaves opposite, compound........(3)
(2) Leaves alternate, radical......*Anemone*
(3) Sepals-4, petaloid, petals-0, no tendril ..*Clematis*
(3) Sepals as many as petals, 4 or 5, third or terminal leaflet modified into tendril ..*Naravelia*
(4) Carpels united at the base; flowers regular ..*Nigella*
(4) Carpels free; flowers irregular ..*Aconitum*

The number at the right hand side of a line indicates the next numbered pair of contrasting choices to be considered.

Identification of Animals with the Help of the Key

Identification of cockroach, prawn, *Pila, Achatina*, a fish (*Osteichthyhes*) toad or frog, Calotes, pigeon and rat up to class with the help of key.

(1) Presence of **pentadactyl** limb and /or post-anal tail ..Phylum chordata-(2)
(1) Absence of pentadactyl limb or post-anal tail Non-chordata (Comprises all the (non-chordate phyla)-(6)
(2) Only post-anal tail present; pentadactyl limb absent but presence of fin with fin rays; operculum present; scales cycloid or ctenoid ..Class Osteichthyes (only bony fish)
(2) No post-anal tail and pentadactyl limbs present (3)
(3) Skin naked, not covered either by scales, feathers or hairs, cloacal aperture rounded ..Class Amphibia (toad or frog)
(3) Skin either covered by scales or hairs or feathers ..(4)
(4) Skin always covered by scales, cloacal aperture transverse ..Class Reptilia
(4) Skin either covered by feathers or by hairs ..(5)
(5) Body covered with feathers, presence of beak; forelimb modified into wing ..Class Aves (pigeon)
(5) Body covered with hairs; presence of mammary gland ..Class Mammalia (rat)

(5) Body covered with chitinous cuticle ..Phylum Arthropoda (7)

(6) Body not covered with chitinous cuticle ..Phylum Mollusca (8)

(7) Body divisible into head, thorax and abdomen; Class Insecta, thorax with three pairs of legs; one pair of antennae (Cockroach)

(7) Body divisible into head and thorax only; thorax with more than three pairs of legs; one pair of antennules; and one pair of antennae ..Class Crustacea (prawn)

(8) Operculum absent ..Class Gastropoda (*Achatina*)

(8) Operculum present ..Class Gastropoda (*Pila*)

Section IV

12 Marks.

Man and Environment

CHAPTER 26

Human Population—Growth and Distribution

troduction

Biosphere is the part of earth's surface pable of supporting life. It includes lowing three main components. 1) Living tter which includes various organisms.) The organic and inorganic mineral product ated by living matters, e.g. coal, soil, mus and litter. 3) Mineral materials formed y the association of living organisms and -living nature, e.g. the gas is output the lower layers of the atmosphere, mentary rocks, clay, minerals and water, . The biosphere consists of interacting logical functional units called ecosystems. h ecosystem has two major components— otic or physical environment comprising , sunlight, temperature, soil, rocks, minerals, etc. and biotic or biological ponent composed of millions of species of nts and animals including man. Within an ecosystem, a species exists as a population whose growth and decline are affected by the capacity of the ecosystem to provide the requirement of life.

Man being the dominant species in the ecosystem with highly developed brain has evolved a language for communication. He can think, plan and make use of tools to create new environmental situation. In this process, he modifies natural ecosystems considerably depending on his own social and economic needs. Agriculture and urbanisation are two of the obvious examples of his ability to create new ecosystems and environments at the cost of natural ones.

In order to understand the dynamics of population growth it would be necessary to examine the population growth curves of other organisms such as yeast. Under

laboratory conditions, yeast cells show a sigmoidal or S-shaped growth curve (Fig. 26.1). This has three phases, viz., the early phase of little or no growth, the middle phase of rapid or geometric (exponential) rise, and the last phase of zero growth (called stationary phase). The early phase (the lag phase) occurs in which the small population of cells adapt to or stabilise with the growth conditions before embarking upon their multiplication. Once the small population is stabilised, it multiplies rapidly because of the plentiful availability of food and other requirements of life. Soon the amount of food available declines in proportion to the number of individual cells and this leads to the onset of stationary phase. During this phase, the number of new cells produced roughly equals the number of dying cells and there is no net increase in cell numbers.

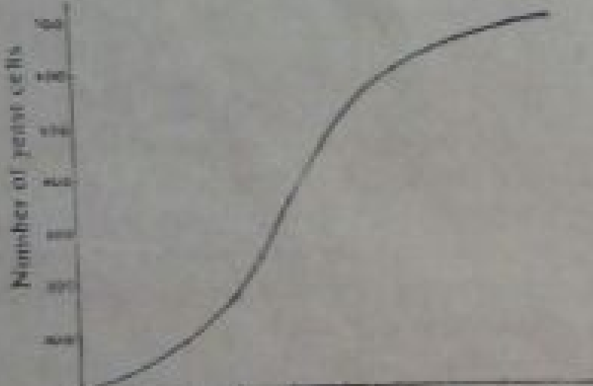


Fig. 26.1 The S-shaped growth curve of yeast cells.

Another type of growth curve experimentally observed in the case of small populations of reindeer growing in a predator-free natural environment having plentiful food is J-shaped (Fig. 26.2). The small population of reindeer initially took time to become adjusted to the new environment and therefore showed no increase. Soon after their adaptation to the new environment, they started multiplying exponentially. As long

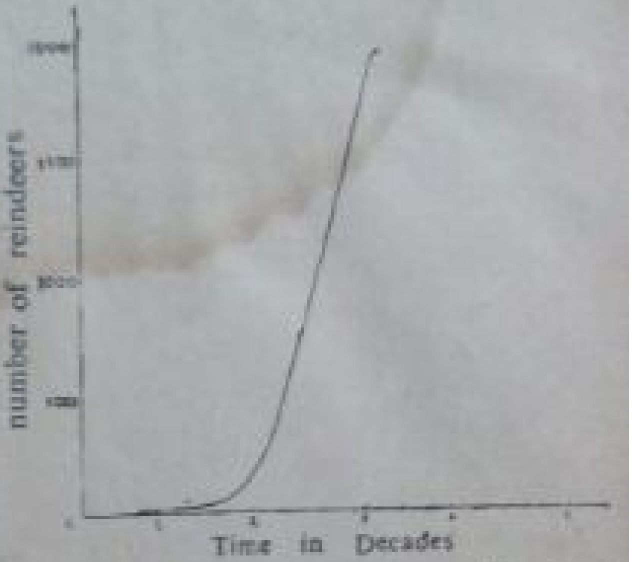


Fig. 26.2 The J-shaped growth curve of reindeers in a natural predator-free environment having plentiful food supply.

as plenty of food was available, exponential growth continued. In due course, the rate of low population to high food supply in the environment changed to the ratio of high population and low food supply. This resulted in mass starvation and mortality thus giving rise J-shaped pattern rather than the S-shaped pattern of growth curve as observed in the case of yeast cells. However, most commonly observed pattern of growth curve applicable to many microorganisms, plants, animals is the familiar S-shaped curve and not the J-shaped curve as described for the reindeer. Although man has inhabited this planet for the last 50,000 years, his population seemed to be in the lag phase upto about the seventeenth century A.D. It seems to have entered the exponential growth phase only in the eighteenth century. It would be hard to speculate on the future of human population growth curve, i.e., whether it will be S-shaped or J-shaped.

Any population does not continue to rise indefinitely as the various factors play a determining role in controling the population size of any species. The importance of such environmental factors influencing the population growth were for the first

[illegible] in 1778 recognised by British Economist [illegible] the same Thomas R. Malthus who stated [illegible] population grows geometrically whereas [illegible] means of its subsistence grow only [illegible]rithmetically. This would cause an imbalance [illegible]tween the growth in the means of subsis[illegible] and in the growth of population; when [illegible] imbalance becomes too pronounced, [illegible] some factors like hunger, epidemics, [illegible] war would reduce the population to a [illegible] compatible with the means of subsis[illegible]. Such population balancing contin[illegible] were termed as 'positive checks' by [illegible]. Modern medical practices have [illegible] abolished epidemics of disease and [illegible] greatly prolonged human longevity. [illegible] has also devised methods to increase [illegible] means of subsistence by major advances [illegible] technology, agriculture and medicine.

[illegible] distribution of population is not [illegible] throughout the world. This un[illegible] of population is described in terms [illegible] population density which is defined as [illegible] number of individuals of species per unit [illegible]. The density of population in a country, [illegible] district or village is obtained by [illegible] total number of individuals present [illegible] area or region by unit area. A con[illegible] or country may have a large part of [illegible] land area not worth habitation because [illegible] the extensive occurrence of forests, [illegible] or deserts. Naturally, then its [illegible] population would get concentrated [illegible] small, fertile land areas. In that case, its [illegible] density would be lower than [illegible] of a country or a region where its entire [illegible] land area is worth habitation. As [illegible] compared to developing countries, the more [illegible] and developed countries have re[illegible] larger land areas in relation to their [illegible] size and this is why the average [illegible] density in developing countries [illegible] than that in developed countries. The [illegible]-land ratios of Africa, the USSR [illegible] America are equal and, therefore, have [illegible] population densities. In the case of Europe, this ratio is higher than that of Asia. The Netherlands is much smaller than India and yet its population density is higher (319 persons/km^2) than that of India (188/km^2). The reason for this difference is that while all parts of the Netherlands are habitable, it is not so in India.

It is difficult to correlate the density of human population with any factor such as economic development, land fertility, etc., because a number of interacting factors are responsible for determining the population density. In general, two basic concepts of ecology-biotic potential and carrying capacity play a major role in determining the size of natural populations. Biotic potential refers to natural increase of population under optimum conditions (non-living) while *Carrying capacity* refers to the upper limit of available resources.

Consequences of population density

As the population density of a country increases, the per capita income, the availability of land, wood, minerals, fuels and other resources decrease and are accompanied by serious economic, socio-political and environmental problems.

Factors controlling population density

The factors which determine the pattern of population distribution and its changes are often complex and varied such as (1) geographical factors like climate, location of water, soil, energy, mineral resources, transportation, etc., (2) socio-economic factors and (3) demographic factors.

Climate

The north and south poles are free of human habitation mainly because they are extremely cold and also agriculturally unproductive. Similarly, tropical conditions are not conducive to human inhabitation because

they are a breeding ground for various infectious diseases and also because the prevailing heat and humidity reduce man's work efficiency. But because of suitability of tropical lands for agriculture, the tropics have been the most ancient centres of human civilisation in countries such as Egypt, India and China.

Location of water, soil, energy and mineral resources

Human settlements occur in places where adequate sources of water are available.

The fertility of the soil for farming is another important determinant of population distribution. Soils of river valleys are very fertile, followed by volcanic soils. The main basis of the highly dense populations in the Indus valley and the Indo-Gangetic plains is the nature of the soils in these regions. The poorest quality soils are the red and yellow coloured soil extensively distributed in the tropics, Africa and Latin America, and the soils found in the Arctic and sub-Arctic regions.

In certain places both iron ore and coal and other fossil energy sources are located close together. Industrial cities based around steel plants have come up in Bokaro, Durgapur, Bhilai and Rourkela. The development of resource-based industries is one of the main determinants of urbanised population growth.

Transportation

Means of transportation have played an important role in the redistribution and dispersal of population. This enabled people to live far away from the source of produce. The low cost of *transportation* and the ready availability of cheap fossil fuels made it possible the development of the urban-industrial state from a purely agrarian society.

Urbanisation

Prosperity in the cities is the basic cause of continued urban growth.

Some important consequences of increasing urbanisation are : (1) overcrowding, leading to problems of sanitation and sewage disposal; (2) transportation and associated traffic problems, (3) environmental pollution generated by industrial activities and automobiles, (4) noise pollution and (5) various socio-economic and cultural changes and problems related to juvenile delinquency and crime. Urbanisation involves progressive increase in the use of our fertile agricultural lands for housing new industries, factories, government offices, schools, hospitals residential quarters, etc.

Demographic factors: The birth rate, death rate and the rate of natural increase (= birth rate-death rate) are called vital rates because any change in these parameters will determine the overall population growth.

The birth rate (natality rate) is the total number of new individuals per unit of time per unit of population. Whereas the death rate (mortality rate) is the number of individuals dying in a given period. These rates vary not only from region to region, but from time to time depending upon the environmental factors. The following table (26.1) shows the various demographic rates in world, developed and developing regions. The striking case is of high death rates in developing region as compared to the

TABLE 26.1
Average annual birth and death rates per 1000 individuals (1978)

Region	Average annual birth rate	Average annual death rate
World	32	12
Developed regions	16	10
Developing regions	37	13

veloped regions. The natural increase is so exhibited by high birth rate and low ath rate over the world.

It is primarily the decrease in death rate ther than increase in birth rate that s led to increase in populations all er the world and more specially in countries e India where the birth-death rates per 00 persons were 46:44 in 1901 and fell 37:14 in 1973, representing an increase annual population growth rate from 0.2 r cent in 1901 to 2.3 per cent in 1973.

The population of India in 1976 was about 600 million to which 12 million people are being added annually.

Countries with a wide gap between birth rate and death rate tend to have a population age structure in which a higher percentage of its population consists of pre-school and school-going age groups. In contrast, country with a low birth rate or a narrow gap between birth and death rates would contain relatively much lower proportion of pre-school and school-going age groups.

EXERCISES

1. Define ecosystem. How has man affected the natural ecosystems?
2. What are the factors that affect population growth? Illustrate your answer with the example of yeast.
3. What is an S-shaped growth curve and how is it different from the J-shaped growth curve.
4. Define the terms biotic potential and carrying capacity. How are these useful in human population studies?
5. Explain the Malthus theory of human population growth.
6. What is the method of calculating population density? How would you account for higher population density of the Netherlands as compared to India?
7. Enumerate the factors which control population density. Explain each factor in detail.
8. What are the factors that lead to the increase in population growth? In what way does the high fertility rate affect a given population.

CHAPTER 27

Soil and Climatic Factors

The human settlement and distribution in different parts of the world in the past and also in the present has followed the pattern of soil fertility and availability of water. Temperature is also a critical climatic factor since it controls precipitation, soil formation and regulates the growth and density of plant and animal populations in any geographical area.

Soil

Soil may be defined as the weathered superficial layer of the earth's crust, capable of supporting life. It is formed by the joint action of climatic factors such as water and temperature, and biotic factors such as plants and microbes. It consists of (1) inorganic materials of the parent rock; (2) organic products of living organisms; (3) living organisms themselves, especially micro-organisms; (4) water film and (5) air filling the inter-particle spaces or pores. The quality of a given soil is assessed mainly on the basis of its fertility, texture, structure, organic content and water-air relationship.

Fertility

The fertility of soil is measured by its ability to support plant life. Plants require various substances: water, gases and mineral nutrients for their growth and reproduction. Oxygen, carbon dioxide and elementary nitrogen are provided by the atmosphere. Oxygen is important for rejuvenation and healthy growth of root cells and other aerobic soil microbes. It is also required for absorption and uptake of mineral nutrients by root cells from the soil. Productivity of soil depends on the availability of water, air and nutrients.

The available supply of plant nutrients in a soil can be reduced by many factors namely, erosion, over-cropping, and by leaching of mineral nutrients. Such soils cannot remain fertile for long, unless the minerals are added artificially. No leaching occurs in arid

regions because there is no water; such soils often accumulate soluble minerals on their surface or beneath the surface, leading to the problem of salinity which is deleterious to crop plants. In humid regions, excessive precipitation causes heavy leaching. Consequently the soils in these areas are often deficient in some major plant nutrients. Nitrogen fixation is an important process carried out by certain bacteria (*Azotobacter, Clostridium, Rhizobium*) and some blue-green algae (*Aulosira* in rice fields, *Anabena, Nostoc* either as free living state or in association with other plants). Blue-green algae are contributors to the nitrogen status and fertility of rice field where they grow luxuriantly. *Anabena* occurs symbiotically within the water fern *Azolla* and this system is very promising and potent nitrogen fixing system. Most of the legumes have nodulated roots. These nodules contain the bacterium *Rhizobium* which fixes nitrogen. In addition, there are some non-leguminous plants also e.g. *Casurina, Alnus, Hippophae* which can also fix nitrogen. Some other natural processes which restore the mineral nutrients lost from the soil include: leaf fall; production of animal and plant wastes, and the decomposition products of animal and plant bodies. However, these restoration processes are generally much slower than the process of nutrients' loss by leaching. Artificial methods are used to maintain the fertility of the soil, especially of crop fields. These include the addition of nitrogenous and other fertilisers, to leave land fallow (the land is allowed to remain uncultivated for a certain time period so that nutrient restoration could occur naturally), and bio-manuring (use of cattle dung).

Texture

Texture of soil depends on the relative proportion of the size of the inorganic particles. The soil based on particle size can be classified as clayey, loamy and sandy.

Clay soils having very fine particles provide (1) greater surface area for chemical and microbiological activity, and (2) better retention of the soil water after the excess has drained away. Sandy soils have poor water holding or retaining capacity whereas the capacity is very high in the clay soils. Clay particles less than 0.001 mm in diameter and function like negatively charged colloids in ion exchange processes in the soil solution.

Structure

This depends on the spatial arrangement of the soil particles of different size classes. The organic matter of a colloidal nature present in the soil functions as cementing material for aggregating soil particles into crumbs. The formation of such aggregates helps to improve the permeability of the soil to water, air and plant roots and root hairs and also increases its water-holding capacity.

Organic content

The chief product of decomposing dead bodies of animals, plants and microbes is humus and it provides food for biologically useful soil micro-organisms including nitrogen fixing bacteria. It is also a good source of various plant nutrients like phosphorus, sulphur, calcium, potassium which are released when humus is further broken down or digested by microbes. Humus is also a source of some organic acids involved in the weathering of rocks, and of some soil colloids which improve the productivity of the soil.

Soil-water and Soil-air

A good soil like silty-loam is one in which about one-half of it is made of inorganic,

organic and biotic components, whereas the remaining half consists of pore spaces in which water and air circulate freely. Air contains gases of which the biologically important gases are oxygen, carbon dioxide and to some extent molecular nitrogen. Oxygen is required for nutrient uptake and absorption and also for the plant anchoring function of the roots. Since oxygen is not soluble in water, water-filled pores create oxygen deficiency which is lethal to the roots, specially in young plants.

The availability of moisture in the soil pores is also essential for proper growth of plants. Plants need large amounts of water both for nutrient uptake and for transpiration. The manufactured food materials, e.g. sugars, are also transported within the plant from one part to another in a soluble form. The transpiration pull is the main force for maintaining a continuous upward movement of the water solution from the roots to the aerial parts of the plants.

Rainfall

Precipitation orginating in the form of clouds may lead to rainfall, snowfall, sleet and hail. Such precipitation is the source of terrestrial water such as rivers, lakes, soil moisture, ground water, etc. The circulation of water molecules through atmosphere and land is called hydrologic cycle (Fig. 27.1).

The amount of water vapour in the atmosphere is, on the average, sufficient enough to cover the entire earth with water to a uniform depth of 2.55 cm. if all the water vapour at a given time were to fall as rain. The atmospheric water vapour which is the evaporation of water from the land water surface, is the source of the observed annual average rainfall. In order to cause an average annual rainfall of about 81cm. the evaporation-rainfall cycle must repeat itself several times a year. Calculations (81/2.5) show that the evaporation-rainfall cycle should operate nearly 32 times in a year to produce

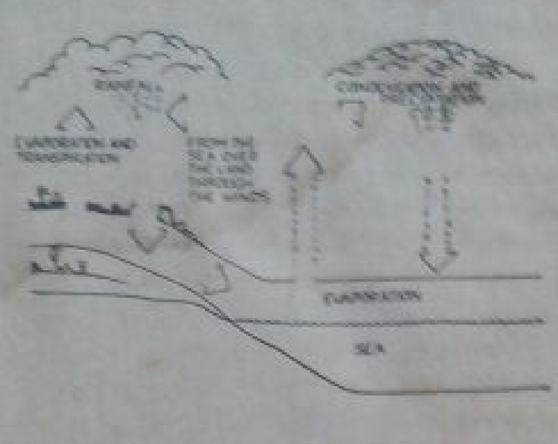


Fig. 27.1 The hydrologic cycle.

the observed annual average rainfall on land. In other words, the life of water vapour in the atmosphere is, on the average, 11.4 days (365/32 = 11.4)

The land gets more water through rainfall than it loses through evaporation, while oceans lose more water through evaporation than they receive through rainfall. This causes a surplus of water on land. This land water supports and sustains various life activities of organisms.

Humidity

When water is found in the form of invisible gas or vapour in the atmosphere, it is called atmospheric humidity and when it occurs in a visible form in the atmosphere, it is called either cloud or fog. The source of atmospheric humidity is the evaporation and transpiration of water vapour from land-ocean surfaces and from plant surfaces. The rate of evaporation depends upon the temperature of water, aridity or relative humidity of the air and the velocity of the wind.

Importance of water

The phrase 'the fire of life burns in water' truly depicts the indispensable role of this substance in the origin, composition, and maintenance of living organisms in terrestrial and aquatic ecosystems.

Water is an essential requirement for living organisms since (1) about 70-90 per cent of the cell cytoplasm is water, (2) living organisms absorb nutrients mostly in the dissolved state in an aqueous solution, (3) water is the ultimate source of hydrogen for the biological conservation of solar energy stored in reduced forms of carbon and nitrogen, i.e., carbohydrates, fats, and proteins, and its release during oxidation with molecular oxygen results in the formation of biologically meaningful form of energy called adenosine triphosphate (ATP); (4) the oxygen of our atmosphere is derived from the photosynhtetic splitting of water into oxygen and hydrogen. Besides, fresh water is needed for drinking, washing, navigation, industrial use, etc. Seawater is unfit for most animals, plants and man.

The unusual thermal properties of water help to maintain a stable climate hospitable enough to accommodate and sustain the diverse forms of life in various parts of the world. For example, a river or lake at freezing temperature, while containing a sheet of ice on its top, still contains liquid water beneath enabling the aquatic animals to survive.

Temperature

Temperature is a qualitative term and refers to the level or degree of molecular activity whereas heat energy is a quantitative term measured in gram calories.

The atmosphere around the earth shows three distinct classes of temperature startification. The one close to the earth and extending upto 10 km high is the troposphere which contains water vapour, dust particles, oxygen, CO_2, nitrogen, clouds, etc., and is alone of direct relevance to the biosphere. Above the troposphere is the stratosphere (Fig. 27.2). This zone is virtually free of water vapour and clouds but contains substantial amounts of ozone. Next to stratosphere is the thermosphere which has no relevance

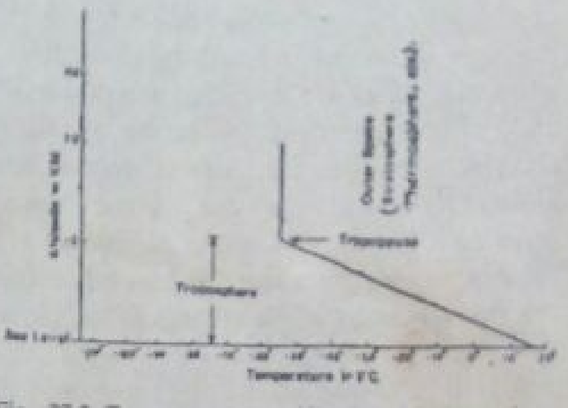


Fig. 27.2 Temperature startification of atmosphere according to altitude.

to the climatic and biological phenomena of the earth. Most of the X-rays and certain other radiations from the sun are absorbed in the outer space before reaching the stratosphere whose ozone layer also prevents much of the ultraviolet light from reaching the troposphere and then the land water surface. This is fortunate since ultraviolet radiation is mutagenic and toxic to living organisms. The troposphere and the land water surface mostly receive the visible light needed for photosynthesis. It also receives the infra-red and long heat waves.

Thirty-four per cent of the total solar radiation consisting of visible light, infra-red and radio waves is reflected by the troposphere to outer space. The reflected waves have shorter wavelengths and do not produce any significant heating effect in the troposphere. Nineteen per cent of the remaining 66 per cent is absorbed by water vapour, CO_2 and other atmospheric components. The remaining 47 per cent reaches the land and water surface; some of this is reflected back to the outer space without heating the atmosphere, a part is absorbed by the land and water surfaces.

The intensity of solar radiation at any place on the earth is governed by the duration of sunlight or length of day and the angle at which sun rays reach that place. The more vertical the incoming sun rays, the greater

will be the radiation energy they carry. Equatorial regions receive more vertical sun rays than middle or higher latitudinal places where the rays are progressively more angular. This is why the equatorial regions are hotter than the regions located towards the poles. Since higher temperature is the requirement for good generation of atmospheric water vapour and cloud formation, the rainy season is normally preceded by high summer temperature.

Since the atmospheric water vapour and CO_2 are main absorbers of the outgoing earth's radiation, a cloudless, clear and dry sky shows a larger difference between the night and day temperatures than a cloudy, dusty and humid sky. This is analogous to a green house effect. In a green house the inside temperature is much higher than outside even though the outside is directly exposed to the atmosphere and the sun's rays. This is because while the glass walls of of the green house permit most of the shortwave solar energy to enter inside, they greatly slow down the escape of the out-going long wave radiation thus causing the inside temperature to rise significantly.

The pattern of vegetation and animal life around the world broadly follows the pattern of temperature and precipitation distribution. Certain bacteria and blue-green algae are thermophilic in that they can tolerate and grow at fairly high temperatures. The yak is an animal adapted to cold temperatures. Conifers are normally the dominant vegetation of cold temperate regions while teak and sal are the dominant trees in tropical areas. In fact, the classification of vegetation types as tropical, temperate, boreal and polar is based on the temperature factor. Temperature controls the metabolic activity of plants, animals and microbes and it is also a factor in the weathering of rocks. It also plays a vital role in soil formation because this process involves abiotic as well as temperature-dependent biotic components.

EXERCISES

1. What are the processes through which soil nutrients are lost and what natural process restores them? What is the justification of using artificial methods of maintaining soil fertility?
2. How do soil water and air affect the quality of soil?
3. What are the major sources of water on the earth? What is a hydrological cycle, how does it operate and affect climate ?
4. What is a green house effect ?
5. Explain the effect of rainfall and temperature on the animal and plant life.
6. Describe the classes of temperature stratification.

CHAPTER 28

Natural Resources

The needs of man are diverse and he uses variety of natural resources. The most important resource being the energy which is obtained from fossil fuel such as coal, oil, and natural gas. Wood and dry dung are the common energy source for cooking in most of our villages.

Classes of Earth Resources

Earth contains two main types of natural resources, viz., inorganic containing air, water, mineral fuels, metalliferous ores, stones, etc., and organic comprising plants, animals, microbes and their products. Some examples of organic natural resources are food plants and animals, wood, coal, oil, natural gas and forests. Soil is an example of both inorganic and organic resources because its formation includes inorganic components derived from weathering of rocks and organic components resulting from the activity of plants, animals and microbes on the weathering rock surface. Depending on abundance and availability, natural resources can be classified into three kinds, viz., (1) inexhaustible, i.e., those not likely to be exhausted by man's consumption and other uses; these include air, sand and clay; (2) renewables, which are naturally replenished after man's consumption; some examples are water, wood, natural pastures, etc., and (3) non-renewable, which cannot be replaced after use; these are fossil fuels, copper, iron and other ores.

Fossil fuels are non-renewable. Before they are exhausted, alternative substitutes must be found. Renewable resources like water and forests also suffer from unprecedented abuse. Inexhaustible resources like air will never be a limiting factor quantitatively but could become so qualitatively if human population continues to increase at the present rate. Some important components of the non-renewable and renewable natural resources are highlighted below with particular reference to India.

Non-renewable Resources

Minerals occuring in the earth's crust show an uneven spatial distribution throughout the world. Some occur in great abundance in one country and very scarcely, if at all, in others. For instance, North America is rich in molybdenum but poor in tin, tungsten and manganese, whereas Asia (Malaysia, Indonesia, etc.) is rich in tin, tungsten and manganese but deficient in molybdenum. South Africa contains most of the world's gold and platinum but has little of silver. The reasons why certain minerals are concentrated in one country and rare in another are not known. At present nearly 200 of about 2000 known minerals find application in various economic activities of our industrial society. This has resulted in the introduction of entirely new cycles of minerals in the environment. Such cycle of minerals is collectively called the materials cycle and consists of (a) mineral extraction, (b) their conversion into bulk metals, ceramics and chemicals, (c) manufacture of public utility goods such as medicines, metallic structures, household utensils, pesticides, etc., and finally (d) their return to the environment as waste refuse. Energy is used at every stage of the mineral cycle. However, the consequence of the energy driven materials cycle is the progressive deterioration of the aquatic, terrestrial and atmospheric environment.

The earth's reserves are conveniently divided into two main groups, metallic and non-metallic. However, the minerals of crucial importance to man are metallic minerals and the non-metallic mineral fuels, otherwise called fossil fuels.

Metallic Minerals:

The important metallic minerals with large reserves in our country are coal, manganese and iron. Chromite, limestone, dolomite, silica and mica occur in fairly large quantities. We have little reserves of copper, iron, phosphate, gold, silver and lead.

Even for sustaining its current annual rate of crop production, our agriculture needs a constant supply of nitrogenous, phosphatic and potassic (N,P,K) fertilizers. Nitrogenous fertilizers are commonly manufactured chemically by the Haber-Boach process which involves a huge expenditure of fossil fuel and petroleum energy. We are not able to produce the required amounts of nitrogenous fertilizer mainly for lack of cheap sources of energy. About 1.4 million tons of the phosphate fertilizer (P_2O_5) are needed annually for agricultural use. Recently, good deposits of phosphate rocks were discovered in Jhamar Kotra in Rajasthan. Reserves of potash are lacking in India and it has to be imported to meet our growing requirements.

Availability of minerals for human use along the time scale is called lifetimes of earth minerals. Estimates of the lifetimes of various earth minerals have been made. Even if world population remains at its present level and the current rate of consumption of various minerals does not increase, still the world reserves of (a) helium, crude oil, natural gas, Uranium-235, tungsten, copper, lead, zinc, tin, gold, silver and platinum are not likely to last beyond the end of the twentieth century; (b) coal, iron, and chromium are likely to be available until about A.D.2500-2800; and (c) almunium, cobalt, manganese and molybdenum will last upto about A.D. 2100-2200. However, these projected lifetimes of various earth minerals are an overestimate and will be affected by increasing world population and corresponding urbanisation-industrialisation. It is possible to extend the projected life-spans of various minerals by recycling, substitution and synthesis. For instance, plastic wares are substituting metal utensils and household articles, and also in industry. Likewise, copper, zinc and nickel are replacing silver in

coinage. Similarly, the feasibility of biological recycling of plant nutrients such as nitrogen and phosphorus is being established.

Fossil Fuels:

Fuel minerals include mainly the non-renewable fossil energy resources such as coal, oil and natural gas. The rise of the present industrial-urban complexes has been possible due to the availability of energy resources at fairly low prices.

Fossil fuel reserves on which modern industrial-urban complexes are based, are limited. At the present rate of consumption stocks of fossil fuel may be drastically depleted leading to a severe energy crisis. Hence, an alternative energy strategy needs to be evolved which is as cheap as the presently available sources of fossil fuel. Table 28.1 gives the amounts of initial fossil fuel reserves and the amount already consumed on a world-wide basis.

The reserves of the world are substantially higher than the reserves of petroleum and hence may last longer. The harnessing of energy from burning coal or petroleum leads to generation of oxides of nitrogen, carbon, and sulphur which escape into the atmosphere causing air pollution. The leading coal producing countries of the world are China, USSR, USA, Federal Republic of Germany, the German Democratic Republic, UK, India, Japan, Poland, Czechoslovakia, Kuwait, Saudi Arabia, Iran, Iraq, Nigeria, the Libyan Arab Republic and Indonesia. New reserves of oil have been discovered recently in the seabeds and off shore Bombay High in India and in the north sea in UK.

The Index of Energy Consumption has now become a standard measure of the economy, affluence and military might of a country. The per capita daily consumption of energy on the average is highest in America, followed by Canada, UK, Germany, USSR, Japan, Mexico, Brazil and India in the above order. Population-wise, America has about 6 per cent of the world population and consumes about 35 per cent of the world's total energy; Russia contains 7 per cent of the population and consumes 16 per cent of the energy; India has 15 per cent of the population but it uses only 2 per cent of the world's annual energy (Table 28.2).

Industrialised agriculture uses more of petroleum than any other single industry. The growing world population would need more and more food to eat and this can only be possible through mechanised agriculture. The green revolution is a product of mechanised agriculture which employs high yielding varieties of wheat and rice grown at the

TABLE 28.1

Fossil fuels : Initial reserves and total withdrawal

Fuel	Initial reserve	Per cent of total energy content	Already withdrawn (to the end of 1970)	Already withdrawn (during 1970)
	metric tons		metric tons	metric tons
Coal	7640×10^9	89.8	140×10^9	2393×10^9
Petroleum	2100×10^9	5.5	268×10^9	17.69×10^9
Natural gas	2000×10^{12}	4.7	$276.9^* \times 10^{12}$	38.5×10^9

*Production from 1951 to 1970.

Source: UN Statistical Year book, 1972.

TABLE 28.2
Energy consumption pattern of selected nations

Nation	Per capita daily consumption (×1000 kcal)	Proportion of world's energy consumption (%)	Proportion of world's population (%)
USA	230	35	6
Canada	165	3	0.6
UK	145	6	1.5
USSR	85	16	7
Japan	40	3	3
India	6	2	15

Data from Scientific American, September 1971 and from UN Demographic Yearbook, 1970

expense of heavy inputs of nitrogenous fertilisers, water,pesticides and other yield-increasing measures. However, as the cost of petroleum energy increases, agricultural countries like India will have to find suitable alternatives to cope up with the rising cost of petroleum-based mechanised agriculture. One such alternative could be to raise synthetic crops with inbuilt mechanisms of nitrogen fixation and pest resistance through appropriate genetic engineering techniques. This would take time. Meanwhile, another alternative seems to be to use sewage as a medium for growing nitrogen fixing blue-green algae and other algae and to use them as biofertilisers. The photosynthetic nitrogen fixing blue-green algae enjoy good growth in water-logged paddy fields and enrich the paddy soils with their fixed nitrogen. Suitable conditions conducive to good algal growth in paddy fields could be worked out and then adopted on a commercial scale to improve the nitrogen inputs for the paddy crops which serve as staple food for a major fraction of the world population.

Consumption of primary energy sources and the world energy prospects:

The world seems to have used about 1600 million kilowatt-hours of energy from fossil fuels from the beginning of the industrial era up to the end of 1970. The fossil fuel reserves which still remain include about 95 per cent coal, 4 per cent oil and 1 per cent natural gas. The rate of petroleum consumption in the world is increasing annually at the rate of 6 per cent in comparison with its annual growth of population of about 2 per cent. Presently, oil and gas account for about 65 per cent of the world's energy consumption and this figure is likely to rise in the near future. The world's known oil and natural gas reserves are likely to be depleted by the end of this century while that of coal is likely to last much longer but certainly not indefinitely. Some possible alternatives to the critical position concerning fossil fuels are (a) hydro-power, (b) wind power and (*c*) nuclear power.

Unlike fossil fuels which are non-renewable sources of energy, sun, wind and water provide renewable, re-cyclable and non-polluting energy sources. Firewood used for cooking and heating purposes in rural areas represents the stored form of solar energy through photosynthesis. Village folk often destroy valuable trees in order to obtain firewood. Most firewood trees take long periods of time, sometimes several years, to mature. The rate of firewood consumption is many times greater than the rate of its replacement by replantation of firewood trees. This age-old practice has led to considerable depletion of our forest and tree wealth and has also affected soil fertility and aggravated soil erosion. An effective substitute for firewood has been dried animal dung cake, but cattle dung is an effective source of nutrients for crop plants and has been used as biofertiliser since times immemorial. Recently, Indian scientists have developed a technique for using cow dung as a source of cooking fuel as well as a manure. This new innovation is called a 'biogas or gobar gas plant' in which fresh cow dung is added to generate the odourless low pressure gas which can be used for domestic cooking or

heating purpose; the dung residue is very effective manure. A number of gobar gas plants are now in use in some of our villages. Another similar invention of Indian scientists is the so-called 'sun-basket'. In this device, the sun's rays are utilised directly to cook meals. The device absorbs solar energy, stores it and finally, converts it into heat energy required for cooking.

Renewable resources

Renewable resources are those which can be regenerated naturally or artificially. Organic waste products or municipal refuse have great potential in conservation of fossil fuels and they can be used for production of energy and chemicals. Vegetation biomass including wood is in some respect even better than fuel because its sulphur content is negligible as compared to that of coal and its ash can also be used as fertiliser.

Water:

Water is perhaps the best example of a valuable and indispensable resource. It is necessary for all life activities. Water is a renewable resource though subject to considerable abuse and misuse. Being a universal solvent, atmospheric gases and various liquid and solid substances are dissolved in water and, therefore, one scarcely comes across pure water in nature. Natural water, considered nearest to pure water is rain water. But in some cases even this water can no longer be really pure as it can absorb certain pollutants which might seep through the ground. The bicarbonates, sulphates and chlorides of calcium, sodium and magnesium which become dissolved in water on contact with soil generally constitute the mineral impurities in natural water and are also responsible for the phenomenon called hardness of water. Salt-containing waters shorten the life of water heaters, steam turbines, cooking utensils and, when used for irrigation may have adverse effects on crops. Soil salinity is particularly serious in semi-arid regions where the dry air favours a high rate of evaporation, thus leading to deposition of salts. In general, salt concentration of about 75-3500 mg/litre in water is considered safe for use as irrigation water.

Most parts of India except the semi-arid and arid zones of Rajasthan receive an average annual rainfall of about 110 cm which generates about 2.75 million cubic km of water per year. About 0.6 million cubic km of water seeps into the soil thus adding to the ground water storage. India has considerable resources of ground water amounting to about 27 million cubic km which is about 10 times the amount of water produced annually in India through rainfall. At present about 45 million hectares of land are irrigated. This is likely to increase with the availability of more water for irrigation.

The average daily water requirement per person has increased progressively during the progress of human civilisation and in modern technological societies about 350-700 litres of water may be used per person per day. This includes uses such as drinking, bathing and washing.

Freshwater rivers, lakes and ponds are a good source of fish. These fishes can be harvested and eaten as nutritious food. The total freshwater fish production in India in 1951 was 218 thousand tons and increased to 666 thousand tons in 1972. The Government is taking various steps to encourage fisheries and the above figure is expected to rise still further in the near future.

Marine resources:

More than two-thirds of the earth surface is occupied by oceans. In view of the depleting land resources, mankind is turning towards exploration and exploitation of oceanic resources which have largely remained untapped. One important use of oceans is commercial navigation and shipping. Sea-

beds and ocean floors are now known to contain larger reserves of fuel minerals such as coal, petroleum and gas, and also metallic minerals such as manganese and cobalt. Oceans also have a huge wealth of edible fishes and marine animals and also economically important seaweeds and kelps. Agar-agar is derived from certain red seaweeds. Seaweed products find increasing application in cosmetic and pharmaceutical industries. Some seaweeds can be eaten directly as is the practice in Japan and China. Certain areas of the west coast of India are rich in petroleum and oil. These reserves offer a great potential for the economic and industrial advancement of the country. About 70 million tons of marine fish are caught annually, of which just about 1 million ton is caught in India. Some steps have recently been taken to modernise marine fishing technology in India and to press into service modern fishing boats for this purpose and the fish catch is expected to increase by about three or four times within a few years.

Certain potato-shaped nodules or concretions rich in manganese, called manganese nodules, occur in huge amounts in several areas of deep ocean floor in the Pacific Ocean between Hawaii and Mexico and also in the Indian Ocean in the south. These manganese rich nodules also contain some amounts of copper, nickel and cobalt. Ways and means to remove and extract these from the ocean are now available and are being increasingly used.

Some possible uses of marine resources in the future include: (1) planning of floating cities on the ocean surface; (2) manufacture and use of sea-planes which take off from and land on the sea; (3) building of offshore terminals for large tankers; (4) cultivation and farming of seaweeds for food and kelps for gas and energy; (5) production of power from sea-tides and (6) towing of icebergs to long distances such as the one recently planned for moving an iceberg from the north pole to the Arabian sea to provide a source of freshwater for Saudi Arabia.

Animal resources:

Like large-scale cultivation of crops and plants of human consumption, a large variety of animals are also domesticated for food products (meat, milk, eggs) for hunting and for labour. Most such animals are either primary consumers like herbivores or are carnivores. Domesticated herbivores mostly eat agricultural crops or pasture grasses. The growing importance of animal protein in human nutrition has led to the clearing of forests so as to create pasture lands for raising the animals. The cost of meat protein is however much higher than that of plant protein or crop protein mainly because of the investment of a much larger number of calories of useful energy in raising meat animals as compared to raising foodgrain crops. The pressing energy problem and the growing human population may ultimately force the world to become purely vegetarian.

Plant resources :

The current world population is about 4 billion and the food grain production is about 1.33 billion tons. The principal grain crops are rice, wheat and bajra. The carrying capacity of farmlands is limited. Besides, the energy required in raising the grain crops than what is obtained in return from eating the grains, i.e., the net energy balance in a modern agricultural ecosystem, is negative. This implies that either the population growth must be checked significantly or unconventional sources of food such as food from algae and yeast cells must be exploited.

The forest is an important example of plant resource. The significance of a good forest cover would become clear when one

consideres the hypothetical example of what might happen if the Himalayas were cleared of all the forests. In such a case, the Ganga., the Yamuna and other rivers originating in the Himalayas would most likely flood several of our north Indian cities in UP and Bihar and would cause the river-beds to rise due to excessive deposition of silt. Apart from serious effects on the climate, this would also lead to disappearance and denudation of mountains and most of our rivers and land vegetation would be seriously affected.

In India, forests cover about 75 million hectares which is 23 per cent of the total available land area. However, productive forests exist only over one-half of the total forest area. The comparatively low productivity of Indian forests combined with the low per capita forest area is the reason why Indian forests have not so far played a significant role in the economic reconstruction of the country. Proper scientific management, conservation and utilisation of forest wealth is likely to increase their resource value and utility in the future. There is an urgent need to conserve the existing forest resources and to extend the forest area by an additional 10 per cent of the available land area.

Floods take a heavy toll of crops, property, animal and human life every year. They also deplete soil fertility due to erosion.

Vegetation is an effective means of checking the spread of desert. The Central Arid Zone Research Institute at Jodhpur is engaged in the task of minimising the spread of the Rajasthan desert by planting suitable trees and grasses.

Management

The introduction of forestry management methods was necessitated mainly by the wasteful approach of the industrial man for obtaining forest produce. Block cutting, reforestation, pest and fire control are some methods practised in a forest management programme. The sustained yield approach advocates a continuous supply of modest timber crop through a method in which the amount of timber harvested annually is replaced by an equal amount of timber crop growth. Timber trees may take from 15 to 100 years to mature. This knowledge helps reforestation schedules.

The method of block cutting is generally used in forests having even-aged trees, consisting of only very few species. This method is most applicable in the case of coniferous forests. A known area of forest is deforested by cutting down the entire tree population of that area; this area may be in the centre of interior of the forest and the last forest area is replaced by reforestation of an adjacent area of the same size. The net result is a sustained supply of forest products without adversely affecting the original size of the forest. For example, one can use a 15-acre land area for afforestation in which each acre is forested every year. After the entire 15-acre area has been forested, one finds graded age difference in plant species growing on different one-acre plots i.e., the plants growing in the last forested acre are one year old, then those on the first acre would be 15 years old. If the tree planted matures in 15 years, then the first planted trees would be ready for cutting 15 years after planting and in this way a one-acre area could be harvested once each year in a graded pattern. The annual deforestation is followed by annual reforestation of the deforested areas. In this way the forest is conserved and at the same time its yield is sustained.

Forest management has multiple uses. Forests are effective in controlling flood and soil erosion. The rising trend of river floods in India is primarily due to loss of some forest areas as a result of indiscriminate and excessive tree felling. In some cases the use of forests as range lands for livestock foraging has caused considerable damage to forest reserves.

Forest constitutes the best habitat for wild life and conservation of forest and wild life are inter-related. The Vindhya range forests in the Varanasi division, once an ideal habitat for game animals including lions, no longer harbour any tiger or lion.

Serious diseases of forest trees are caused by parasitic fungi such as rusts, smuts and mildews, viruses and insects. Insect-mediated control of a wild plant species is well ilustrated by the insect 'bug' feeding on the weed *Lantana*. This bug devours *Lantana* so fast that it may be used to control *Lantana*. This is an example of biological control in which biological agent is used to check undesirable species. Some work is also being done to breed forest trees showing resistance to fungal, viral, and animal diseases.

The trunks of forest trees constitute the main source of timber. Lumbermen take away the stem logs but leave behind the stumps, leaves, barks and twigs as debris. Additional wastage of forest produce occurs in the saw mills where round logs are cut into squarish or rectangular logs. Recent technological advances have made it possible to use saw dust, the bark and pieces of wood for industrial and commercial purposes. The world's future timber demands require extensive and intensive utilisation and management of forests. Some feasible approaches include: (1) intensification of afforestation or reforestation rates to nearly three times of the present rate (2) further improvement of timber quality through genetic breeding (3) avoiding wasteful cutting and encouraging sustained-yield harvesting, (4) breeding for disease and pest resistant varieties of forest trees and (5) control of diseases of important trees through judicious application of fungicides and pesticides.

Wild life

The term wild life means all those naturally occuring animals, plants and their species which are not cultivated, domesticated or tamed. Large number of wildlife species face extinction. If the current pattern of land use continues and if sound conservation measures are not practised, a substantial part of its biological heritage and genetic resources will be lost.

Most wild animals and plants inhabit forest areas. Any change in the forest environment in terms of food supply and other details would have a corresponding effect on their population. Deforestation leads to destruction of wild life.

A few examples of the effects of deforestation on wild animals are described below. The damage caused to north American forests by the early European settlers was responsible for the extinction of the passenger pigeon, a species which could not survive the disappearance of its forest abode. The pinkheaded duck which used to live in the swampy jungles of India is now no longer encountered, possibly because of changes in the drainage pattern of these swamps. Another threatened species is great Indian bustard which once used to occur in abundance in Rajasthan desert, but is now reported to be only a few individuals. It is on the verge of extinction as a result of indiscriminate hunting, poaching and other causes. Pitcher plant and orchids recklessly exploited are also facing extinction. The number of American buffalo called the bison has been greatly reduced because of indiscriminate hunting for its hide (skin). The hunting of tigers and lions along with deforestation have caused steep declines in their populations.

Our main task in conservation is to set aside representatives of biotic communities and protect wild plants and animals. The biosphere reserve concept of Unesco is an outcome of this need. In the Unesco programme, representative natural ecosystems such as the deciduous forest, the conifer forest, the tropical forest and the tropical grassland, etc., are to be set apart,

as natural reserves. It is hoped that effective practical enforcement of the concept will significantly check the sharply dwindling wildlife populations and also preserve some of our present ecosystems.

Appreciating the desirability of wild life conservation, the Indian government enacted the Wildlife Protection Act in 1972. Despite the existence of this Act poaching (killing of game animals) is still a big national problem. There are a large number of rural poachers active in the tarai belt of the Himalayas. These poachers shoot deer, wild boar, tiger, leopard and a variety of game birds. The meat of herbivore animals and the hides of the leopard and the tiger are sold in the market. Expensive purses and belts are made out of the skin of alligators and the snow-leopard. Some products derived from the musk-deer and bear also fetch a lot of money for these poachers. Efforts are now being intensified to curb the activities of poachers with a view to saving our wildlife resources from further destruction and depletion.

Resource-based Environmental Problems

Man has mostly tended to engage in faster and faster economic exploitation of his valuable resources without any serious consideration of the ecological aspects or consequences. He has used (or misused) huge amounts of precious fossil fuels. Considerable amounts of this non-renewable energy resource can be saved minimising air pollution resulting from burning of petroleum products. Increasing use of nitrogenous fertilisers and pesticides in agriculture has aggravated the problem of water pollution. Deforestation has led to soil erosion, loss of soil fertility and recurring floods, Industrialisation and urbanisation have accentuated the problems of waste disposal, sanitation, and provision of clean air. To these may be added the growing problems of feeding and housing the ever-increasing human population. The need of the hour is to evolve methods of pollution control, conservation of energy, conservation of water, soil and metallic minerals, and at the same time increasing the carrying capacity of the earth with reference to man. Man has just started to realise the dimensions of the resources problem and environmental pollution; he has to act now to minimise the indiscriminate use and abuse of his environment, to control his population size to manageable limits, and to evolve strategies for best possible use of land and sea resources on a short and long term basis. The successful accomplishment of above goals would need a global effort, a global approach, a global legislation and a global organisation.

Relationship between Conservation and Development

Development generally means economic growth and advancement related to mass production of various commodities and consumer goods. The emphasis is always on increasing the production of commercial produce, sometimes at the risk of polluting the environment. For example, agriculturists are always interested in bringing more and more of forest areas under pasture for agriculture and for herding larger and larger number of meat or milk yielding livestock. It is this kind of development-oriented progress that has caused environmental instability and degradation.

Ecology is the science of inter-relationships between environment and the living communities including man. Environments and biotic communities are interacting complementary units. For example, our aerobic atmosphere is the result of the plant photosynthesis and the latter is possible only because of the continued availability of sunlight. Excessive hunting of herbivorous animals often leads to starvation of their predator carnivores in a forest. Bringing the forest land under the plough causes the native

wild animal species to emigrate or die. The natural environment has also been modified in a way that has caused the extinction or disappearance of natural scavengers or decomposers. This in turn affects the self-cleansing property of the environment and further accentuates the severity of man-made environmental pollution.

Both the economic development plans and the policies for conservation of nature aim at improving the quality of human life. The former mainly considers the material aspect of the quality of life, whereas the latter covers the material, ecological and aesthetic aspects. Another difference between the two is that whereas the gains of economic activities are realised quickly, those of conservation plans are realised slowly and over a long time period. The conservation approach considers the developmental activities of man in relation to their impact on natural biota, climatic factors, water and soil resources; the economic approach takes into account methods which yield profits quickly. However, both economic progress as well as nature's conservation share the common goal of increasing human happiness. The natural conservation approach is preferred by the ecologists mainly because it is scientifically sound and rational and has prospects for the long-term future of man. Ideally, an engineer, a forester, an agronomist, a range manager, a wildlife specialist, a landscape architect, an economist, and an ecologist should effectively participate in any development planning of a city or industry. They should keep in view the basic ecological principles that govern the functioning and stability of ecosystems.

An agricultural crop ecosystem is more unstable than a forest mainly because these ecosystems are typically single-species (monoculture) ecological units and do not have the biological diversity which is an essential foundation of stability of an ecosystem. Biological diversity means that a large number of different species of plants and animals live together as biotic communities in an ecosystem. The members of each biotic community are interlinked by the food chain. Human activities can shorten the existing food chains in several ways. For example, man can hunt all the lions of a natural forest and thus leave the predator-free deer to uncontrolled multiplication for so long as their food supply remains sufficient. Eventually the deer population would face mass starvation and death because of their population size exceeding the carrying capacity of the forest. In this way, lion hunting shortens the plant deer lion food chain to a plant → deer or plant → decomposer chain. In other words, man-made changes in the food chain cause drastic reduction in biological diversity with a proportionate decrease in the stability of an ecosystem.

Largely as a result of excessive deforestation, many wild animal species have already become extinct or are now facing extinction. The basic understanding of rules governing feeding inter-relationship in a biotic community has highlighted the abuse of forest and wild life. The need for conservation of forest and wild life conservation is now fully recognised.

EXERCISES

1. Enumerate the different categories of natural resources. Illustrate your answer with examples.
2. What are the various categories of non-renewable natural resources ?

3. What are mineral and fossil fuel resources of India? Why is there a need to conserve the non-renewable resources? What are the various ways in which these resources can be conserved?
4. List the various renewable natural resources of the earth. How can they be conserved ?
5. Describe the methods of conserving plant resources? Mention in brief each of these methods.
6. What is the relationship between conservation and development? How these inter-relationships improve the quality of human life?
7. Explain the various methods of forest management.
8. What factors lead to the extinction of wildlife? Suggest methods for checking further extinction of wildlife.

CHAPTER 29

Environmental Pollution

Pollution is generally defined as an undesirable and excessive addition of substances to water, air and land which adversely alters the natural quality of the environment. The term environment includes the air, water and land. It also includes biota including buildings, landscape, oceans, parks, open spaces, vehicles and noise. The environment is complex and comprehensive and is affected by all our activities.

A pollutant can be defined as a constituent in the wrong amount, at the wrong place or at the wrong time. For instance, nitrogen and phosphorus are essential nutrients for living organisms and are extensively used in agriculture to increase crop yields but they can also cause pollution in lakes and rivers when found in excess by promoting undue algal growth. All pollutants are not necessarily wastes. Some are used to increase one resource but they pollute another.

Various pollutants weaken our plant and animal populations and sometimes even prove lethal. Pollution stresses also exert selection pressures on the genetic variability of natural populations. In some cases, organisms exposed to pesticides have developed adaptive resistance to pesticides, and plants growing near mines can adapt to acquire resistance to toxic metals.

The mode of action of many pollutants is highly complex. This was demonstrated from recent observations on declining populations of predatory birds, such as, hawks, eagles, falcons, the heron and the brown pelican. The dwindling breeding capability of such birds has been attributed to a weakening and thinning of their egg shell which in turn occurs as a result of birds having eaten pesticide-poisoned insects or organisms.

The recent upsurge of interest and growing concern for the quality of our environment has strengthened the concept of environmental monitoring which requires regular,

periodical measurements of environmental characteristics followed by timely assessment and interpretation of the data obtained. Reliable monitoring data are essential to identify pollution problems, to prescribe environmental quality standards, to plan pollution strategies and to provide an early warning system for unforeseen pollution problems.

Air Pollution

Air pollution is now a serious problem for those living in big, congested, industrialised cities with heavy vehicular traffic. In large urban areas some major environmental pollution problems include noxious fumes, dust and grit, corrosive gases, excessive noise, smoke, offensive odours arising mainly from factories processing animal wastes and food residues.

Air pollution may be defined as the occurrence or release into the atmosphere of any foreign materials or gases which are harmful to man, vegetation, animals or buildings. The burning of coal, or other fossil fuels releases considerable amount of sulphur compounds such as sulphur oxides into the air. These are powerful pollutants. Another major source of air pollution in big cities and industrially advanced countries is the automobile (cars, motor vehicles). Most vehicles burn their fuel rather inefficiently and incompletely thus discharging only partially oxidised combustion products into the atmosphere. When exposed to sunlight, these products, consisting mostly of hydrocarbons and nitrous oxide, produce ozone and other pollutants. In fact, the automobile is often considered as the greatest polluter of the atmosphere and is responsible for about 75 per cent of the noise and about 80 per cent of air pollution in big cities.

Some more important pollutants in the atmosphere of big cities like Calcutta, Bombay and Delhi are carbon monoxide, oxides of sulphur and nitrogen, hydrocarbons, metal dust fluorides, pesticides, fly ash, soot, and occasionally radioactive substances. Fly ash is particulate and consists of non-inflammable mineral fractions of ordinary coal-soot, on the other hand, is inflammable but becomes released in the unburnt state as soot. Cotton dust is an important pollutant in Ahmedabad, Surat and other areas having textile mills. Citizens of Delhi and Bombay are familiar with the thick, black smoke and soot that come out from chimneys of factories and electricity generating plants which burn coal and soot. Recent estimates of the magnitude of air pollution in Calcutta and its suburbs indicate the release of about 630 tonnes of diverse pollutants every day, and these come from more than 2,000 industrial establishments, two thermal power stations, about 1.5 lakh motor vehicles, and a considerable number of steam engines, mechanised boats, ships and aeroplanes. A few other sources of this heavy pollution are the bituminous coal used as cooking fuel, charcoal and firewood. To some extent these above pollutants are an inevitable consequence of advancing civilisation and industrialisation, but as living standards rise, man-made atmospheric pollution is felt first to be a major irritant in that it causes loss of amenity (i.e., it makes life less pleasant) and later as a serious threat to health. Some kinds of pollution may even render certain areas quite unfit for normal habitation, thereby constituting a major obstacle to socio-economic progress.

Certain air pollutants, e.g., pollen, spores or cells of fungi and lower plants, volcanic gases and marsh gas are produced naturally. Salt aerosols are derived from the natural sea-spray.

Various metallurgical processes release dust or fumes containing metallic pollutants, e.g., lead, chromium, beryllium, nickel, arsenic and vanadium. Some metals such as cadmium, zinc and mercury are released

into the environment from the refining of zinc, copper, lead and steel, and the manufacture or use of pesticides, phosphatic fertilisers, fungicides and cosmetics. Such agricultural activities as crop spraying and dusting for pest and weed control are responsible for emitting organic phosphates chlorinated hydrocarbons, arsenic and lead into the air.

Major Air Pollutants and their Effects

Air pollution produces a variety of adverse effects including offensive odours, loss of atmospheric clarity, soiling of clothes, buildings and manufactured goods by soot, smoke and dust. Airborne fluroides, ethylene and sulphur dioxide, damage crops and other plants and cause dental and other injury to cattle grazing in pastures contaminated with airborne fluorides. Air pollution also corrode metals and paints. Ozone attacks rubber products. Various atmospheric pollutants also cause bronchitis, respiratory diseases and allergic reactions.

Certain epiphytic lichens (*Paramolia usnea, Cladonea*), and bryophytes (mosses) are reliable indicators of air pollution and can often be ranked in a sensitivity scale to estimate changing levels of atmospheric pollution, especially the content of SO_2. The presence or absence of certain common but sensitive species of epiphytic lichens and mosses in a given locality and the pattern of their distribution can be related to the extent of pollution in that area over a certain period of time.

Sulphur Oxides and Particulates

Both particulate and gaseous pollutants (e.g., sulphur oxides) commonly occur together and are commonly produced during the burning of fossil fuels like coal. The addition of various particles to sulphur dioxide enhances or potentiates the effects of SO_2 on animals. The extent of respiratory distress in animals and men exposed to sulphur oxides has been found to vary with pollutant content of the atmosphere. Vegetation is even more sensitive to SO_2; considerable damage to various plants occurs at annual geometric mean concentrations of SO_2 as low as 60-70 ug/m^3. This can be seen in areas like Chembur in Bombay, close to fertiliser plants.

Some effects of SO_2 and its transformation products in the atmosphere on plant cells are illustrated in Fig. 29.1. These include membrane damage, plasmolysis, Chlorophyll destruction, metabolic inhibition, growth and yield reduction.

Aerosols

Aerosols are certain chemicals released into the air with force in the form of a mist or vapour. The widespread use of aerosols in recent years has caused serious concern to environmental scientists. An important source of aerosols in the upper atmosphere is the jet aeroplane emissions. These aerosols contain fluorocarbon (carbon compounds which contain fluorine) propellants and these fluorocarbons deplete the ozone layer in the stratosphere, thereby permitting some more of the harmful ultraviolet radiation to reach the earth's surface. Ozone acts as a preventive shield against ultraviolet rays. The thinning of the ozone layer has also been attributed to nitrogen oxides and sulphur oxides from emissions of supersonic aeroplanes and also to oxides derived from nitrogenous fertilisers. Recently carbon tetrachloride (CCl_4) has been shown to destroy some of the stratospheric ozone. Unlike other chlorofluorocarbons such as CCl_3F and CCl_2F_2 which are commonly used as refrigerant and propellant aerosols and which pollute the atmosphere largely as a result of human activity, CCl_4 seems to originate from natural sources as well as from human activity.

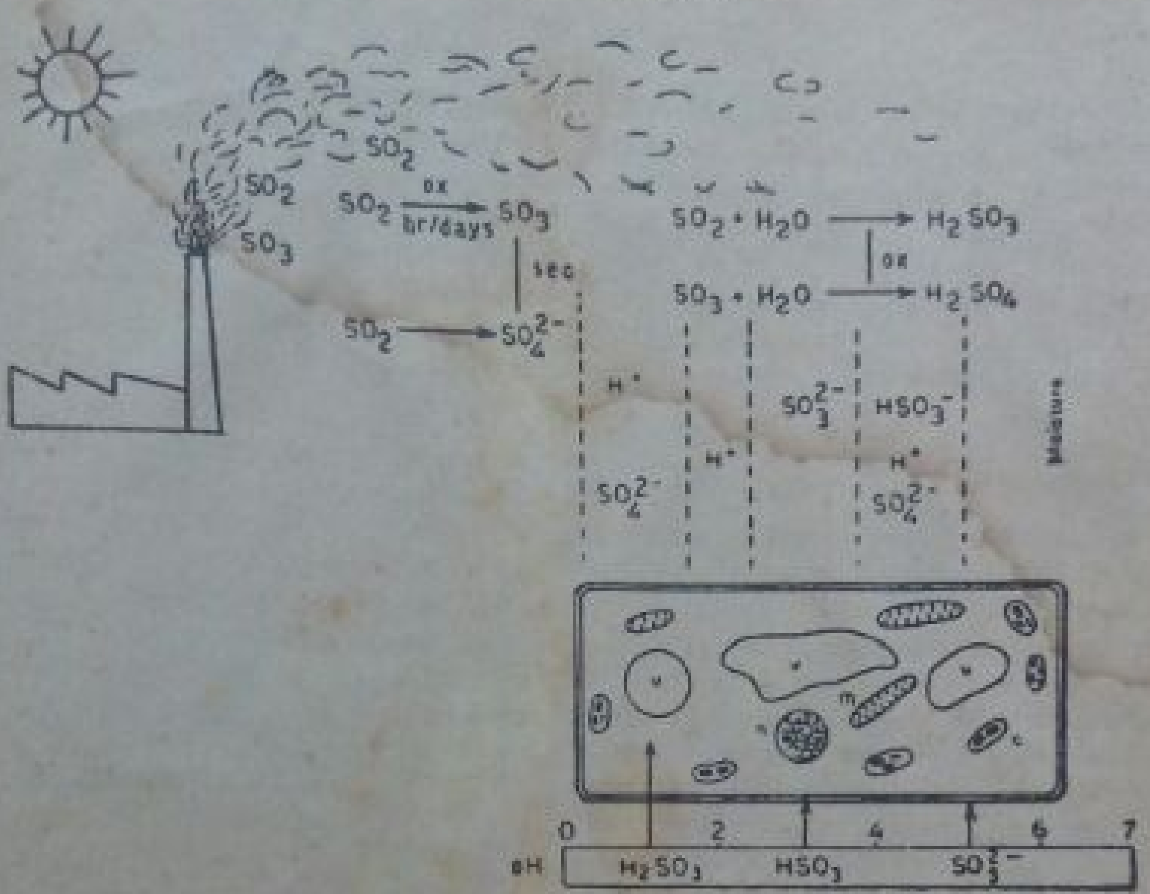


Fig 29.1 Emission and transformation of SO_2 in the atmosphere. Arrows indicate permeability of different SO_2 products into a plant cell at various pH values (c: chloroplast; m: mitochondrion; n: nucleus; v: vacuole).

Carbon Monoxide

Cigarette smoke, motor vehicles, industrial plants, and domestic heating appliances are common sources of CO. The inhaled CO selectively combines with haemoglobin and blocks the oxygen transport function of the latter. Of course, small traces of CO occur naturally in the blood, especially of smokers inhaling tobacco smoke. This natural level becomes elevated on exposure to CO-enriched air and can lead to such symptoms as laziness, exhaustion of body, headache, disturbance of psychomotor function, decrease in visual perception, serious effects on the cardio-vascular system and finally, after prolonged exposure, even to death.

Nitrogen Oxides (NO and NO_2)

Motor veluicles, burning materials and chemical industries are common sources of nitorgen oxides. Possibly, these oxides are harmful to human beings and animals but no authentic health effects have been reported.

Photochemical Oxidants

In the presence of sunlight, various unburnt hydrocarbons (derived from the combustion of automobiles) react with the oxides of nitrogen to form ozone, peroxyacyl nitrates, aldehydes and other complex organic products. At least some of these photochemically produced oxidants adversely affect the respiratory system and the athletic performance of humans, and are particularly

damaging to leafy crops such as spinach and lettuce.

Preventive Measures and Control

It is easier to control air pollution effectively from point sources such as factory chimneys than from other sources. The economic costs of the damage caused by air pollution are generally much higher than the cost of avoiding such damage. Some of our current industrial processes may be suitably modified so as to minimise the extent of pollution control equipment (e.g., electrostatic precipitators and filters) is now available and can be installed in factories so as to minimise atmospheric pollution.

SO_2 pollution can be controlled either by removing the sulphur after combustion or by precombustion desulphurisation of fuel. One way is to substitute our conventional fuels by electricity and natural gas which do not emit SO_2, or by low-sulphur fuels. In fact, cleaning up of combustion and substituting non-combustive modes of energy production are the two methods to minimise atmospheric pollution. Some noteworthy clean and non-combustive means of generating energy include geothermal power, solar power, tidal power and nuclear power. Nuclear power, however, generates some thermal pollution.

Emissions from motor vehicles may be minimised by cleaning the exhaust gases after combustion through the use of a catalyst.

The use of tall chimneys can substantially reduce the concentrations of pollutants at the ground level.

Since the prevailing meteorological conditions effect the dispersion, dilution and mixing of various emissions, a proper operation of factory schedules based on weather forecasts can help in controlling air pollution, e.g., when atmospheric stagnation or calm is predicted, a power plant should switch over from coal to gas.

Water Pollution

Pollution of water is defined as the presence of some foreign organic, inorganic, biological, radiological, or physical (e.g., heat) substance or property in the water that tends to degrade its quality and either constitutes a health hazard or otherwise decreases the utility of water.

Most surface waters contain various extraneous living and non-living materials. These include suspended solids, organic and inorganic substances, bacteria, viruses, algae, protozoans and other biota (see Fig. 29.2). Many of these substances or organisms, when present in very low concentrations, do not cause pollution and some of them may even be a positive asset in improving the quality of water (Fig. 29.3). However, when the concentrations of these materials or organisms are high, they degrade the quality of water and make it unfit for recreational, domestic, industrial or other uses. Thus, what constitutes a pollutant is often dependent on its concentration. However, there are other kinds which act as pollutants even at very low concentrations; these include various industrial poisons, toxic chemicals and pathogenic organisms.

Some pollution occurs naturally in the form of soil erosion, deposition of animal wastes and fallen leaves, solution of minerals in water, etc. Much of it is, however, the direct result of human activity.

Emphasis is generally laid on the chemical and bacterial aspects of water pollution though other aspects of pollution are being recognised as potential hazards to human health.

Major Pollutants and Effluents

Sewage: A major source of pollution is raw or partially treated sewage discharged into rivers, lakes and streams. The discharge of huge quantities of municipal and domestic

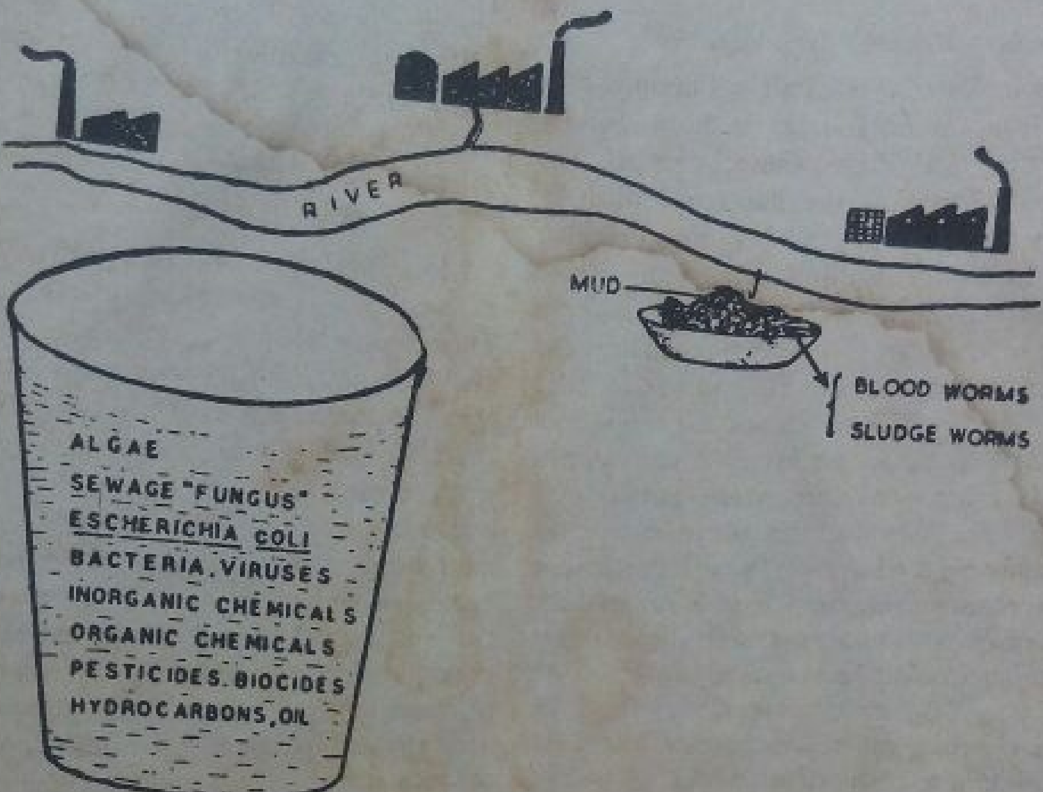


Fig. 29.2 A bucketful of water from a polluted river showing the various kinds of pollutants likely to be present. Also, a handful of bottom mud from highly polluted river would contain mostly bloodworms and sludgeworms.

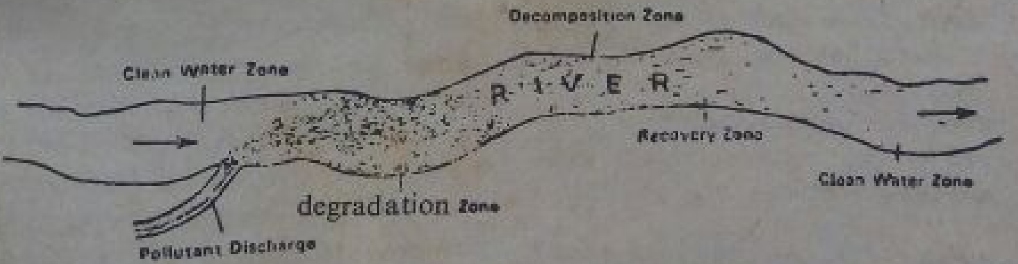


Fig. 29.3 Some typical zones of pollution in a river and the process of self-cleansing and purification as one moves downstream of an effluent outfall.

wastes and sewage into rivers and canals has polluted many of these waterways and even the sacred Ganges is polluted. Most municipal sewer systems not only contain organic wastes and sewage but also a variety of industrial effluents from industries and factories into the municipal sewers. Disposal of sewage into rivers and lakes cause several undesirable effects, e.g., the spread of water-borne diseases. Sewage increases the biological productivity and interferes with many uses of the water body. Wastes containing toxic substances damage biological activity and kill useful organisms.

Sewage is rich in organic substances that provide nutrition for various decomposers (bacteria and fungi) whose population consequently increases in the river. The

decomposition products are liberated into the water and cause pollution. Organic phosphorus is liberated into the water as dissolved inorganic phosphates. This dissolved phosphorus is now recognised as a major pollutant in most surface waters, another major pollutant being dissolved nitrogenous compounds such as nitrates.

Apart from sewage, phosphates, nitrates and ammonium compounds originate from detergents and fertilisers. The inorganic forms of phosphorus and nitrogen are the key nutrients for algal growth. Consequently the growth and multiplication of algae is greatly increased in polluted waterways. These large algal masses decay and lead to deoxygenation of water besides emitting foul smell. Aquatic bacteria can break down only a small amount of dead algae and cannot cope up with very huge amounts.

Inert suspensions: Fine particles of dust, clay, soil, ores are other pollutants of water.

Poisons such as acids, alkalies, phenols, cyanides, copper, lead, zinc, mercury, insecticides and fungicides pollute water.

Inorganic reducing agents such as sulphides and sulphites, and ferrous salts are active under reducing conditions.

Oil from oil spills and washings of automobiles, sometimes pollutes our rivers. Oil pollution from tanker accidents and spills is a major threat to oceans.

Organic residues and effluents from dairy farms, slaughter houses, breweries, tanneries, paper mills and sewage constitute a singificant fraction of pollutants.

Considerable pollution is caused by such industries as leather tanneries, beet-sugar refining and meat-packing. Industrial operations also produce large amounts of various non-degradable and long-lasting pollutants such as inorganic and synthetic chemicals that spoil the quality of water. In fact, about two-thirds of all degradation of water can be attributed to various manufacturing activities, transportation and agriculture.

The rapidly increasing practice of adding large amounts of inorganic fertilisers to crop fields has in some cases been responsible for the nutrient-enrichment (Eutrophication) of our streams, rivers and lakes. A significant fraction of the fertiliser leaches off into nearby waterways where it encourages algal growths. This is more true for nitrogenous fertilisers (which are readily soluble) than phosphatic ones. Nitrate in agricultural drainage contaminates drinking water; on reduction to nitrite in the stomach, it combines with haemoglobin and reduces the oxygen transport capacity of the blood. Nitrite poisoning is especially detrimental to children and may even prove fatal.

In a developing country like ours, it is necessary to use substantial amounts of fertilisers in order to increase crop yields. But this also involves the concomitant risk of environmental pollution. The two opposing interests have to be properly balanced. Unlike inorganic fertilisers, organic manures are highly beneficial though they are slow acting. Supplementation of farmyard or cowdung manure with small doses of inorganic fertilisers can enhance the utility of both. The Fertiliser Association of India has recently suggested a strategy for efficient and optimum use of fertilisers. A judicious application of the correct dose of an appropriate fertiliser at the proper time can minimise fertiliser losses in agricultural run-off. Ammonium sulphate and urea, rather than nitrates, should be preferred for submerged paddy. Ammonium sulphate is particularly suitable for saline-alkaline soils and tea plantations in South India. Nitrogenous fertilisers should be applied in split doses to reduce losses. The International Rice Research Institute in the Philippines has proposed the 'mudball' technique involving mixing of urea or other fertiliser with soil, making balls, and placing them in the reduced zone of paddy fields (viz., 2-3 cm below the soil surface). The mudball

technique enhances nitrogen uptake and minimises its loss through leaching.

Faulty agricultural and forestry practices have also led to transportation of varying amounts of top soil from the land to the river beds, thereby choking the waterways with silt and mud. Pesticides and biocides washed out from the fields into the water are absorbed by various organisms, including fish. Some of these dangerous chemicals are concentrated from water by aquatic organisms; these can be further concentrated in the body of the higher members of the food web (Fig. 29.4). This process is known as biomagnification or biological concentration. Thus, whereas the concentration of a substance like DDT may be extremely low in river water, the carnivorous fishes of the same river may contain such high concentrations of DDT that they become unsuitable for use as human food. Mercury can also be absorbed and concentrated by fishes and other aquatic animals. Some of the mercury discharged into lakes is transformed to the neurotoxic form, methylmercury, by bacteria. Methylmercury is extremely poisonous and is absorbed directly by fish. The main source of mercury pollution is the fungicides used for treating seeds; some other sources are cosmetics, medicines, certain industrial processes and pulp mills.

Most pesticide chemicals have broad-spectrum activity which ensures that non-target organisms are also affected in addition to the intended targets. Surviving pesticide residues are even more dangerous ecologically than the pesticide itself, these residues are mostly uncontrollable and unpredictable in action. Those pesticides whose toxic effects cannot be confined to the site of application should be totally banned. Pest control should be viewed basically as an ecological rather than a chemical problem. In some cases accurate monitoring of pests helps in planning effective pesticide use. By keeping a regular account of numbers and composition of pest populations. pesticide applications can be timed and planned more rationally.

Our national development and progress depend on mass production of food and fibre and on prevention of disease. Pesticides constitute a tool to make this possible and hence we need them. However, pesticides are poisons and, being dangerous, they must be used with utmost care. Over-application or misuse has to be avoided. Biological and chemical research must make pest control a more efficient and safer process than before.

The quality of waste water is generally measured in terms of its biochemical oxygen demand (B.O.D.) which represents the amount of dissolved oxygen that is needed by bacteria in decomposing the wastes. The B.O.D. test is the most important measure of the polluting capacity of organic effluents; it is not very reliable for assessing inorganic or purely industrial pollution. It is an arbitrary measure of the oxygen taken up by a sample of effluent or river water during a period of five days at 20°C. The B.O.D. test should not be regarded as a chemical reaction; it is essentially bacterial. Clean water has very low B.O.D. value, whereas organically rich water has very high B.O.D.

Chemical oxygen demand (C.O.D.) is a more general measure of all oxygen consuming materials in a waste.

Effects of Effluents and Pollutants

Effluents produce physical, chemical and biological changes in water. Some pollutants produce only a temporary effect on water whereas others have a long-lasting effect. The five main kinds of physical and chemical effects of pollutants are: (1) addition of poisonous substances, (2) addition of suspended solids, (3) addition of non-toxic salts, (4) water deoxygenation and (5) heating of the water. Some effluents, e.g., sewage, can produce all five of these effects

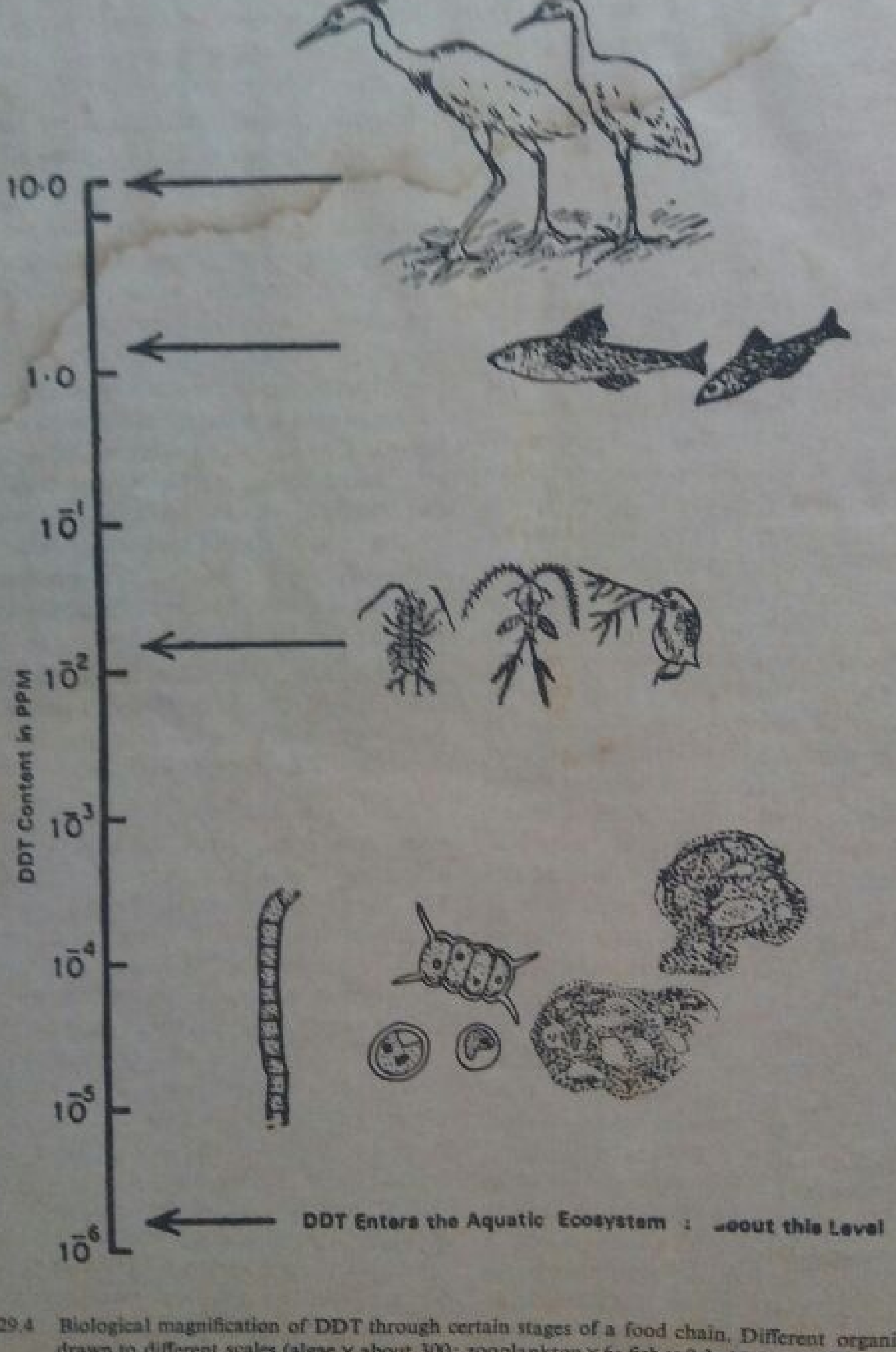


Fig. 29.4 Biological magnification of DDT through certain stages of a food chain. Different organisms are drawn to different scales (algae × about 300; zooplankton × 6; fish × 0.3; birds × 0.1).

whereas other effluents may produce only one, two, or more of these effects.

Most large bodies of water such as lakes and rivers possess some self-cleansing ability. Some pollutants settle down to the bottom while others are bleached by sunlight; still others are consumed or degraded by decomposer microbes provided that there is sufficient oxygen present to sustain microbial activity. However, if the pollution load becomes too heavy, then severe deoxygenation can result and the self-purification of the river is inhibited.

Aquatic organisms can tolerate poisons and other pollutants only in low concentrations. Excesses prove lethal. Such organisms as Daphnia, trout and other fishes are fairly sensitive to most poisons. Different species of micro-organisms, plants, and animals have different levels of tolerance or sensitivity to various effluents or poisons, and the toxicity of most poisons is also affected by environmental factors such as temperature, pH, oxygen content, calcium content, etc. Waterways polluted with zinc and lead often become biologically barren. In some other forms of pollution, certain indigenous species are eliminated but other, more tolerant, species replace them. Suspended solids tend to eliminate algae and rooted plants and also alter the fauna by blanketing over the river bed. In extreme cases only a few animal species such as blood worm and sludge worm survive. Pollution with organic matter not only involves deoxygenation of water but also the addition of suspended solids, ammonia and sulphides, and the organic matter itself. Organic effluents always contain certain bacteria of which the most common is *Escherichia coli*. The different bacterial species present break down cellulose, starch, fats and proteins, others bring about nitrification, and still others reduce sulphates to sulphides under anaerobic conditions.

Certain species of fungi, colonial bacteria, algae, and lower animals form fairly large colonies or flocs in sewage polluted water. These flocs are collectively called sewage fungus. These flocs of sewage fungus may be white, red, yellow, or brownish. The main constituent of sewage fungus is the bacterium *Spherotilus natans*; other notable constituents are *Beggiatoa alba*, *Leptomitus sp.*, *Carchesium polypinum*.

Polluted waters also harbour various diatoms, blue-green algae, *Oscillitoria* and *Microcystis* and such green algae, *Senedesmus*, *Stigeoclonium* sp. When pollution is not excessive, such macrophytes as *Potamogeton pectinatus*, *P. natans*, and the moss *Fontinalis antipyretica* also occur in addition to sewage fungus. Certain bacteria eating protozoans of polluted water are *Colpidium*, *Glaucoma* and *Paramecium*. The diversity of species numbers in highly polluted water is commonly very low but the number of individuals of the few species that do occur can be very large indeed.

The physico-chemical and biological effects of an organic effluent on a river as one passes downstream from the outfall are diagrammatically illustrated in Fig. 29.5.

The oxygen content of water falls sharply from the site of outfall for some distance downstream and then recovers gradually. The B.O.D. content of water declines gradually. There is a great increase in bacterial numbers at the release of effluents into a stream and bacterial content is restored back to normal slowly as the effluent becomes diluted downstream. The populations of blood worm, sludge worm and *Asillus* in a relatively unpolluted stream are fairly low. When an effluent is discharged into such a stream, these populations are not much affected for a short distance downstream but then they begin to rise, attain peak values after some distance in keeping with the inorganic content and finally declines slowly to the original levels as the organic matter is oxidised.

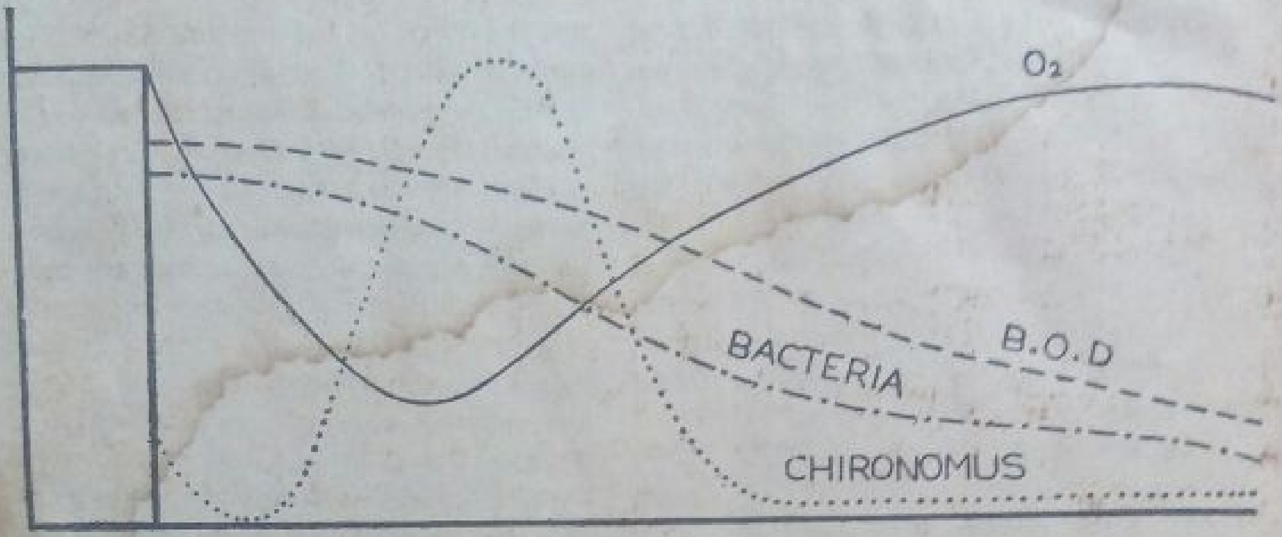


Fig. 29.5 Physico-chemical and biological effects of organic effluent on a river. Horizontal axis indicates distance down stream and vertical axis shows outfall.

Treatment of Waste Water

The sewage and factory wastes have to be cleaned to some extent before they flow into waterways. The primary and secondary treatments are basic methods to remove most pollutants from waste water. Primary treatment employs physical processes such as screening, shredding, sedimentation and flotation. It results in the settlement and removal of most suspended particulates as well as of some oxygen-demanding wastes.

Secondary treatment makes use of microbial activity to oxidize waste materials. The two common secondary treatment processes are the trickling filter method and the activated sludge process. In the former method, waste water is passed through a thick bed of gravel stones where bacteria consume most of the organic matter. The resulting water, which is now much less polluted trickles out through the bottom of the bed and is transported elsewhere through pipes for further treatment. In the activated sludge process, the sewage is pumped after primary treatment, into an aeration tank where it mixes with air and sludge containing some algae and bacteria. These bacteria break down up to 80-90 per cent of the organic matter and the algae generate oxygen for bacterial growth and multiplication. The water is then chlorinated to kill the disease producing germs.

Recycling of Water

Various kinds of pollutants and wastes can be effectively recycled and this constitutes one of the best means of prevention and control of pollution. The recycling of agricultural and agro-industrial wastes is particularly important because of the wide and extensive base of material available. Profitable utilisation of such wastes as paddy husk, tobacco waste, corn cobs, wastes of sugar and paper industries, forestry wastes and slaughter-house waste is now possible. About 25,000 tonnes of fruit and vegetable wastes accumulate each year in India and at least 275 million rupees are lost annually owing to improper utilisation of wastes from slaughter-houses. Some good examples of waste utilisation in India include the conversion of coconut and agricultural wastes into paper and board, and jute wastes into hardboard. The seeds of neem, mahua and other trees can be utilised for producing oil-cakes and fats. One of the best examples

is the gobar gas plant which gives the farmer not only gas for domestic cooking use but also enriched cow-dung manure. Until recently, most of the *Shorea robusta* seeds in our Sal forests were wasted but they are now being collected for extraction of fat.

Composting is an effective method of waste disposal. Recourse to composting minimises the risk of environmental pollution; nutrient and humus-rich wastes may be reutilised by replenishing depleted soil resources. Health hazard is eliminated since pathogenic organisms are destroyed during composting, and wastes are disposed of on one's own home ground rather than on the neighbour's doorstep.

A significant fraction of all the paper used in developed countries today is recycled paper.

Soil Pollution

Soil is the most important component of the earth's crust (lithosphere). It supports the vegetation which in turn supports animal life. Like air and water, soil is also subject to pollution. Any substance that is common (e.g., minerals) or foreign (e.g., organic pollutants) to the soil system which adversely affects the productivity of the soil is termed a soil pollutant; soil productivity in this definition includes both yield and the quality of the food products produced. Whereas pollution of air and water can spread to long distances, that of soil is generally localised and any pollution of the soil of one field need not always affect the soil of a neighbouring field. Apart from soil erosion which is a kind of negative pollution, soils are exposed to three main sources of pollution viz., (1) pollutants washed out of the atmosphere; (2) pesticides and biocides and (3) artificial fertilisers. The first two of these can alter the basic structure of the soil and may prove lethal to essential soil organisms; they can also make the soil toxic for plant growth. Most inorganic fertilisers also spoil the quality of agricultural soils in the long run and differ from organic manures which are highly beneficial in this respect.

Landscape is an important part of our environment, and the urban landscape is particularly, prone to some form of pollution. Landscape pollution may or may not necessarily involve the introduction of noxious substances into the environment. *Positive* pollution entails the introduction of undesirable elements, e.g., pesticides and industrial wastes. These pollutants may cause notable changes in soil insects and other organisms. Negative pollution means the excessive use and removal of a particular resource in a landscape or soil. Such over-use can have striking visual as well as more deep-seated socio-economic and ecological consequences. Soil erosion resulting from overgrazing and depletion of the cover in semi-arid regions is a good example of negative pollution.

Loss of soil productivity due to erosion, unplanned irrigation, overgrazing, deforestation and other defective agricultural practices lead to formation of deserts. Deserts cover nearly 40 per cent of the land surfaces, and are marching in every continent destroying arable land, uprooting livestock and seriously threatening food supplies. In India the Thar desert spreads annually over 12,000 hectares of productive land. Some attempts to check the march of the desert have been made but have not been very successful. The goat is probably the chief culprit that prevents desert reclamation and afforestation activities in Rajasthan. The large population of goats and other grazing animals prevent the survival and establishment of saplings and trees planted to check spread of the desert.

Land has considerable capacity for purification of waste water. Its fertility is increased by absorption of reasonable amounts of waterborne nutrients. However, some of these substances become pollutants under

certain circumstances. A variety of solid wastes such as garbage, trash, ashes, sludge, building materials and rubble, empty bottles or cans, etc., are dumped on land and cause considerable nuisance. Such solid wastes are sometimes called the 'third pollution' and constitute a serious problem in affluent countries where there is a widespread 'throw-away' psychology; many commodities such as milk, beer, juices and other products are packaged in disposable containers which are thrown away after use and cause the third pollution. One objective of solid waste control is the displacement of wastes from locations where they are positively utilisable. One means of positive use is the sanitary landfill where untreated waste is buried in layers and covered with earth. Such a landfill represents a kind of recycling as the buried material can be later utilised in various ways.

Pollution Caused by Radioactivity and Chemicals

Increasing use of diverse variety of chemicals and radioactive substances in agriculture, industry and medicine create problem of pollution and environmental concern. Certain *radiations*, e.g., the electromagnetic waves used in photosynthesis and in photomorphogenetic processes of plants and animals are biologically useful for normal functioning of species, communities, ecosystems and biosphere. Certain living organisms can withstand adverse environmental conditions, for example bacterium called *Micrococcus radiodurans* can tolerate such high doses of harmful ultraviolet (UV) and X-rays as would kill other organisms. Some species of leguminous plant *Astragalus* grow in soils containing high concentrations of the toxic element selenium without showing any pathological symptoms.

Some chemicals, e.g., nitrogen, hydrogen, oxygen, potassium, calcium, phosphorus, sulphur, magnesium, iron, etc., are normal growth nutrients for various organisms. Others such as mercury, lead, arsenic and chlorinated hydrocarbons are toxic to one or the other component of the biological food chain. Such chemicals occurring in soil, air or water are deleterious both to man and the ecosystems.

Harmful Radiations

There are two kinds of harmful radiations: (1) non-ionising, represented by UV light and (2) ionising, including X-rays, γ-rays and particles. Damage from non-ionising radiation results from absorption of the incident radiation by the cellular components leading to formation of toxic photoproducts. In contrast, ionising radiation damages living cells mainly by physically breaking the macro-molecules through the process of ionisation. The biological effect of non-ionising radiation is mediated by cellular components which absorb them: that of ionising radiation is not mediated by molecules specifically involved in their absorption. Consequently, the biological effects of non-ionising radiation are more specific whereas those of ionising radiation are more general.

The visible light forms a small fraction of electromagnetic radiation spectrum (Fig. 29.6). This visible light perceptible to the human eye extends from about 400 nm. in the violet to about 700 nm in the red part. Most of the green plants absorb blue violet radiation of wavelength range about 450-480 nm and red light of wave length about 660-680 nm and they utilize these in their photosynthesis. Between about 200-400 nm lies the ultraviolet rays. X-rays and gamma rays have still smaller wavelengths. Infra-red rays have wavelength longer about 700 nm. These and some other forms of radiations are illustrated in the figure.

Ultraviolet Radiation

The ultraviolet rays occur as natural component of solar radiation and much of this component is absorbed by the ozone-

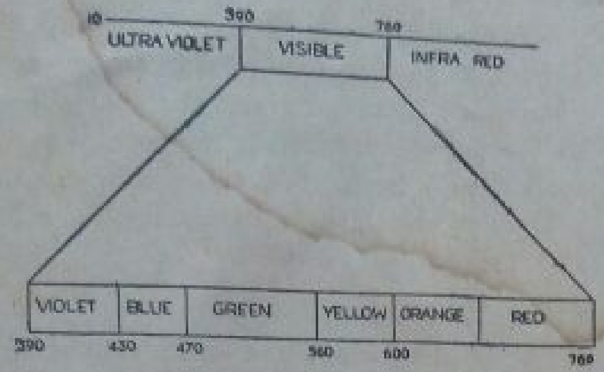


Fig. 29.6 Electromagnetic radiation spectrum.

containing zone of the stratosphere before reaching the earth's surface. UV is abosrbed effectively by water of the biosphere, by photosynthetic pigments of plants and by proteins, RNA and DNA of living organisms. Biological chemicals which absorb UV become inactivated. The UV-inactivation of DNA is biologically more hazardous because whereas the UV-damaged pigments, proteins or RNA can be regenerated by the intact (undamaged) DNA, the damaged DNA cannot regenerate these molecules nor can they by themselves produce new (undamaged) DNA molecules. However, cells have mechanisms which enable them to repair the damaged DNA to normal form, one such repair system which requires light of longer wavelengths (longer than 300 nm) to neutralise the damaging effect of UV, is called photoreactivation. An enzyme called photoreactivating enzyme is involved in this process. Another type of repair mechanism which may operate either in dark or light, and which acts on all kinds of damaged DNA (photoreactivation repairs only UV damage) is also known. It protects animals, plants and microbes from the lethal and mutagenic effects of UV light.

The skin of certain persons is extremely sensitive to the UV component of sunlight. This skin disease is known as Xeroderma pigmentosum. It afflicts only those individuals who lack the UV repair mechanisms.

In plants, carotenoids protect the cells from UV damage. This is ecologically important since plants are rooted in soil (immobile) and require sunlight (which also contains the harmful UV) for photosynthesis. In the absence of carotenoids, the UV would kill the plants.

The ozone layer of outer space screens out some of the UV from the sunlight. The release of halogen containing hydrocarbons from aerosol spray cans and jet propellant emissions into the atmosphere have been reported to damage or thin out the protective ozone shield. When this happens, some more of the UV possibly reaches the earth's surface thereby causing damage to life on earth. It is believed that this may accentuate the incidence of cancer and harmful mutations in man and other organisms.

Ionising Radiations

Some of the artificially generated ionising radiation are X-rays used in medical sciences, and radioactive wastes of atomic or nuclear reactors. Naturally occurring radioactive elements and cosmic rays constitute what is called background radiation. The three common forms of ionising radiation from radioactive elements are: alpha-particles, beta-particles and gamma rays. The primary cosmic ray particles possess extremely high amounts of energy.

Biological Effects of Ionising Radiations

Ionising radiations exert short-range or acute effects, which are expressed within a few days or weeks after exposure to radiation or the long range effects which are seen over a longer time period. Radiation induced short-range effects are physiological and morphological in nature leading to physical crippling or immediate death of the exposed organisms. Global interest now centres around the long range or delayed effects of radiations. Such effects may include genetic changes, mutations, increased inci-

dence of tumours and cancer, shortening of life-span and growth and developmental changes.

The use of ionising radiation for sterlisation and preservation of food stuffs is now widely practised in several countries. These methods have been introduced in India by the Atomic Energy Agency. The successful application of radiation technology in food processing industries is mainly based on the fact that ionising radiation is preferentially destructive to life processes of the exposed system and not to the quality of food.

Natural background radiation has been the source of low doses of ionising radiation over the millenia during which life has evolved and progressed to the stage of man. During this period the role of background radiation might have been to induce mutations in wild populations for evolution to take place. At present the explosion of nuclear test devices, atomic bombs, etc., are adding to the amounts of background radiation. It is this man-made addition of ionising radiation to our environment which causes great concern and poses serious hazard for future of man.

Hazards Associated with Nuclear Fall-out

The two main radioactive elements in the nuclear fall-out are Iodine-131 and Strontium -90. Iodine participates in the formation of thyroxine and is, therefore, an essential requirement in animals for the proper functioning of their thyroid glands. The normal stable Iodine-127 and its unstable radio-isotope I-131 are chemically indistinguishable by biological systems. Plants contain little iodine and animals get their iodine requirement through food chain. The concentration rises as one moves up along the food chain pyramid from the producer level (plants). Since biological systems cannot differentiate between the two forms of iodine, they take up either or both forms indiscriminately, depending on their relative proportions, I-131 thus can enter the food chain at any level and become concentrated in the terminal component through the process of biological amplification. Since man himself is often the last link of many food chains, I-131 often gets concentrated in the human body. Once within the body, it can damage white blood cells, bone marrow, spleen, lymph nodes, and can cause lung tumours, skin, cancer, sterility, defective eyesight, etc.,

Strontium-90 can replace calcium in plants and animals. Plants require calcium mainly for the formation of middle lamellae of cell walls. In animals the main role of calcium is in bone formation. Radioactive strontium can also enter the food chain and get concentrated in human beings just like radioactive iodine. Being a bone-seeker, Sr-90 would mainly cause bone cancer and tissue degeneration in most animals and man.

Absorption of radioactive elements as nutrients by aquatic algae often leads to their accumulation in fish beyond permissible or safe levels. Two common examples of radioactive isotopes biologically magnified in food chains are Phosphorus-32 and Zinc-65. Cobalt is also a nutrient of both plants and animals and Co-60 and Co-58 are produced as radioactive wastes in nuclear fission processes.

Protection Measures

The sun is the natural source of UV while high-pressure mercury vapour lamps (called germicidal lamps) are the normal laboratory or clinical sources of UV light. Eyes are very sensitive to UV and, therefore, we must protect the eyes against UV while working with UV light in the laboratory. Since UV cannot penetrate through glass, glass spectacles or goggles should be worn. Visible light neutralises the UV damage considerably and hence exposure to sunlight of any individual exposed to UV constitutes a good remedial measure to treat the individual. UV has

very low penetrating power through body tissues. It is, therefore, a biologicaly ineffective source of radiation for multicellular organisms. In contrast, ionising radiations are highly penetrating. There is no known method to stop the background radiation (ionising) but its dose is so lov that it poses no serious health hazard. It is only in the past few decades that man has produced ionising radiations and radioactive vastes to pollute the atmosphere and water. An effective protective measure would be one where the leakage of radioactive elements from nuclear reactors is prevented. The next step is to store the radioactive wastes in places where they gradually decay to their final sta e products without causing significant biological damage. Nuclear technology, its know-how of methods used for the handling and safe disposal of radioactive materials and radiations are matters of national security and national choice.

EXERCISES

1. Define pollution. What is a pollutant and how does it affect the environment, animal and plant life?
2. What is the concept of environmental monitoring?
3. List the various sources of air pollution, and discuss their effects.
4. What are the various sources of water pollution? Name some important constituents of effluents. Suggest some methods for the prevention of air and water pollution.
5. What are the various sources of soil pollution and their effects on the environment?
6. Mention the major groups of harmful radiation.
7. What are the various chemicals that are harmful to living organisms?
8. What is ultraviolet radiation and what are its sources? What would happen if ultraviolet radiation from the sun is not absorbed in the stratosphere?
9. Describe the harmful effects of ultraviolet radiation.
10. What are the various natural and artificial sources of ionising radiation and their harmful effects?
11. What are the chemical hazards associated with the nuclear fall-out? Give some methods of protection against them?